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FIELD PERFORMANCE AND QUALITY CONTROL CONSIDERATIONS OF INSITU LYSIMETERS TO MEASURE INFILTRATION INTO LANDFILLS THROUGH THE FINAL COVER

PHASE ONE FINAL REPORT
JUNE 1996

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Ontario

Ministry of
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Report prepared by:
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Report prepared for:

Ontario Ministry of Environment and Energy

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ABSTRACT

A two phase study was initiated by the Ontario Ministry of the Environment (MOE) in 1981 to use insitu lysimeters to measure the amount of water that infiltrates into landfills through various types of covers under varying conditions. Phase one was to develop a reliable, practical lysimeter design. Phase two was to use this design to measure the infiltration under various conditions, and to compare infiltration estimates determined by standard methods.

Several lysimeter designs have been tested and improved upon since the study began in 1981. This report discusses data obtained between October 1991 and October 1994 and is considered sufficient to show the effectiveness of the final lysimeter designs.

The infiltration rates measured in the final lysimeter design of Phase one show that there are discrepancies between identical designs at the same site. It is felt that with improvements made to the data collection practices and some additional field tests, some of these discrepancies could be fully explained and the overall results improved. However, it is anticipated that the efforts required to initiate and complete Phase two would not be worthwhile when compared with other field methods that are being used to determine overall average infiltration rates.

1.0 INTRODUCTION

The major source of water in landfill leachate is that which has infiltrated through the cover of the landfill. Increasingly, covers for domestic and hazardous waste landfills are being designed to control this infiltration to reduce the impact of contaminants from these facilities on the environment, in particular to ground water supplies.

Current cover designs are based in part on equations that use empirical values derived from agricultural engineering. Unfortunately, however, there are no field measurements of the performance of such covers on existing landfills that would demonstrate that these cover designs are valid and that infiltration is as predicted by the equations. This issue is important to the collection and treatment of leachate, assessing the extent and concentration of the contaminant plume, and estimating costs and design of contingency plans required by the Ministry of the Environment and Energy (MOEE).

The objective of this study was to collect field measurements of the actual amount of water which infiltrates through various types of final covers for landfills under various conditions. The data collected would be tested for reproducibility and compared to the results expected using the existing empirical calculations of infiltration. Phase one of this study was to design, construct, install and test a device (the lysimeter) that would measure the amount of infiltration through the final cover of a landfill site. This device should be practical and suitable for use as a regulatory tool to estimate and verify the amount of infiltration through the final landfill cover.

Phase two of the study would proceed only if the ability of these lysimeters to obtain sufficiently reliable data was demonstrated. Phase two was to involve the construction of additional lysimeters to evaluate the effect on infiltration of various parameters associated with landfill cover design. These parameters include:

1) cover material (thickness, type, porosity, compaction, fractures, etc..);

2) position of the lysimeter on the landfill (ie top, side or toe of landfill);

3) slope; and

4) vegetation (amount and type)

The field results were to be compared with those predicted by modelling software used by landfill designers.

2.0 BACKGROUND

In August 1981, the Ontario Ministry of the Environment (MOE) requested proposals for the design and evaluation of an infiltration collection system (see Appendix A "The Original Request for Proposal"). Gartner Lee Associates Limited (GLAL) completed the design and installation of five lysimeters in early 1983 at the Britannia Road Landfill site, Mississauga, located in the Region of Peel. Two different lysimeter designs were tested and monitored over a sixteen month period (March 1983 to July 1984). A detailed description of the construction and installation of these two designs is provided in Appendix B.1.

A final report by GLAL was submitted to the MOE in March 1985. The report contained evidence that leakage could be occurring in some of these lysimeters and therefore, an investigation of the lysimeters was initiated by MOE. The investigation took place from September through October 1985 and found that all the lysimeters had failed. The failures were mainly caused by differential settlement of the storage well, and clogging of the intake pipe to the storage well.

MOE modified the lysimeter design resulting in two lysimeters that were virtually identical except for the type of material (drainage tile versus gravel) used for the storage zone area. Six lysimeters, three of each design type, were installed at the Britannia Road Landfill by MOE and Peel Region personnel in August 1987 (see Appendix B.2 for details of lysimeter installation and designs).

The six lysimeters were monitored by Ecologistics Limited from September 1987 to April 1989. In the fall of 1987 and early winter of 1988, the hydrographs revealed that the lysimeters were not performing as expected since the water levels were fluctuating substantially. It was suspected that barometric effects on a trapped air layer between the water in the storage zone and the overlying recompacted clay layer caused the water level fluctuations. To overcome this problem, vent holes were drilled into the side of the well casing of each lysimeter. This field modification to the lysimeters, completed by late April 1988, did eliminate the barometric effects; however, as discussed below, the vent holes caused other problems that were not foreseen.

On August 12, 1988, two of the six lysimeters were excavated and sacrificed to inspect the structural integrity of each lysimeter type (drainage tile and gravel). It was found that both were still intact structurally.

In August 1989, the MOE took over the responsibility of monitoring the lysimeters. In October 1989 it was noticed that the infiltration at three of the lysimeters was unreasonably high. It was determined that water was entering into the storage zone of these lysimeters through some of the vent holes that had been drilled inadvertently in the well casing within the final cover material. All vent holes presumed to be located within the final cover material of the lysimeter were plugged by January 1991. All data collected by the MOE from August 1989 through to January 1991 were presumed to be of limited value.

In September 1989, three identical lysimeters were installed at the Guelph municipal solid waste (MSW) Landfill Site and at the Barrie MSW Landfill Site by Ecologistics Limited. These lysimeters were slightly modified versions of the design used at the Britannia Road Landfill Site (see Appendix B.3 for details of lysimeter installation and design).

The lysimeters at the Guelph and Barrie sites were monitored by Ecologistics Limited from January 1990 through to September 1991. The construction, installation and monitoring results of the Guelph and Barrie lysimeters are described in Ecologistics reports entitled "Quantification of Infiltration Through Landfill Covers", August 1991 and "Monitoring Infiltration Through Landfill Covers", March 1992. MOE took over the management and monitoring of the Guelph and Barrie lysimeters in October 1991.

This report provides the final status of Phase one and examines data collected at the Britannia, Guelph and Barrie sites from October 1991 to October 1994.

3.0 LYSIMETER LOCATION, DESIGN AND CONSTRUCTION

3.1 Site Locations

MOEE monitored ten lysimeters at three different landfill sites. Four lysimeters were installed at the Britannia Road Landfill Site in Mississauga which is situated on the Second Line West south of Britannia Road. Three lysimeters were installed at the Guelph Landfill Site which is located on the eastern outskirts of Guelph with access off Eastview Road. Three lysimeters were installed at the Barrie Landfill Site which is located just west of Barrie off an access road that extends to Ferndale Avenue.

3.2 Design and Construction

As discussed in Section 1.0, the principal intent of Phase one was to develop a reliable, practical lysimeter design that would measure the amount of infiltration that occurs through landfill covers. Once a candidate design had been found, the next step was to further assess the performance of the design under a range of conditions found at representative landfill sites. In order to accomplish such an assessment, at least three lysimeters were installed at each landfill. This number provided a means for assessing the ability of the lysimeter to achieve reproducible measurements. In so far as possible, the lysimeters were installed under the same conditions at each landfill site. The cover thickness, soil density, soil cover material, vegetative cover and slope were the same for all lysimeters at the same site. This reduced the number of variables as much as possible, and therefore the amount of infiltration collected from all the lysimeters at the same site should be similar.

To minimize the uncertainty in variations that could occur because of the effects of surface water running off or onto the lysimeter surface area, all lysimeters were located in relatively flat areas of the three landfill sites. The Guelph and Britannia lysimeters were positioned slightly downgradient of the top of the landfill on a terraced slope and the lysimeters at the Barrie site were positioned at the very top of the landfill.

Maintaining a good vegetative cover on all of the lysimeters at the three landfill sites was not achieved (see Appendix C "Lysimeter Cover Material"). The lysimeters at Guelph and Barrie sites were re-seeded in October 1991 and June 1992 respectively but the vegetation never became established. All the lysimeters at Guelph and Barrie sites had vegetative covers that were very patchy to bare. To assist in establishing a good vegetative cover at the Britannia site, sod was placed on all the lysimeters in November 1991. By the summer of 1993, bare patches became prevalent on all four lysimeters. Although there are bare patches adjacent to the lysimeters, they were more numerous on the lysimeters at each of the landfills, and therefore they appear to be related in some way to the lysimeters and not entirely related to the typical vegetation regress which can occur on landfill covers.

A circular bare section (approximately .3m radius) around the outside of each of the monitoring wells was observed throughout the monitoring period except for a temporary period at the Britannia site when the sod was first placed. The cause of the vegetation regress around the monitoring wells is likely due to the effects of the bentonite seals and/or mastic skirts which were installed immediately below the ground surface around the monitoring wells. It was originally thought that the vegetation regress was related to an insufficient seal around the outside of the monitoring wells which in turn allowed a preferential pathway for landfill gas to exit. However, this was not supported by data from the continuous hydrographs which did not exhibit any sharp increases. Such increases would indicate the presence of preferential path ways for water to move down the outside of the monitoring well and into the storage zone (see Section 4.2.2.1).

Figure 1 shows the basic design components of the lysimeters. A more detailed description of each lysimeter design is provided in Appendix B. Although there are three different lysimeter designs, the differences are considered minor and are not felt to have affected the overall results. The following steps were taken to construct the lysimeters:

- an excavation approximately 4m x 4m x 1.5m deep was made into the refuse
- filter cloth was placed in the bottom of the excavation
- a wooden frame was used to support the flexible membrane liner (40mil/93mil PVC liner); the liner essentially formed the walls and floor of the lysimeter
- a layer of sand was placed inside the liner
- patio stone to support the monitoring well was placed in the centre of the lysimeter within the sand layer
- filter cloth was placed over the patio stone and sand layer
- a monitoring well was centred on the patio stone above the filter cloth
- the storage zone material (pipe or gravel) was placed inside the lysimeter
- filter cloth was placed over the storage zone material
- a layer of sand was placed on top of the filter cloth
- the final cover material was recompacted until the area was flush with the surrounding landfill cover
- a cover was placed over the monitoring well

Of the three lysimeter designs, two were constructed at the Britannia site, and the third at the Guelph and Barrie sites. The main difference in the two lysimeter designs at the Britannia site was the type of material used for the storage zone (plastic pipe or gravel), otherwise, the two designs were essentially alike. A detailed description of the two lysimeter designs at the Britannia site can be found in Appendix B.2. To improve the utility and operation of the lysimeters installed at the Britannia site, some modifications were made for the Guelph and Barrie lysimeters. Three of the more major modifications are outlined below:

a) to provide more storage capacity, 600mm diameter perforated Big "O" heavy duty drainage tiles were used to form the storage zone;

b) to provide rapid air and water exchange between the storage zone and monitoring well, slots were cut in the monitoring wells to the top of the storage zone;

c) to prevent preferential flow down the outside of the monitoring well, bentonite seals with and without a Mel-rol membrane mastic skirt were installed around the monitoring well at several different lifts during construction of the final cover.

A more detailed description is provided in Appendix B.3.

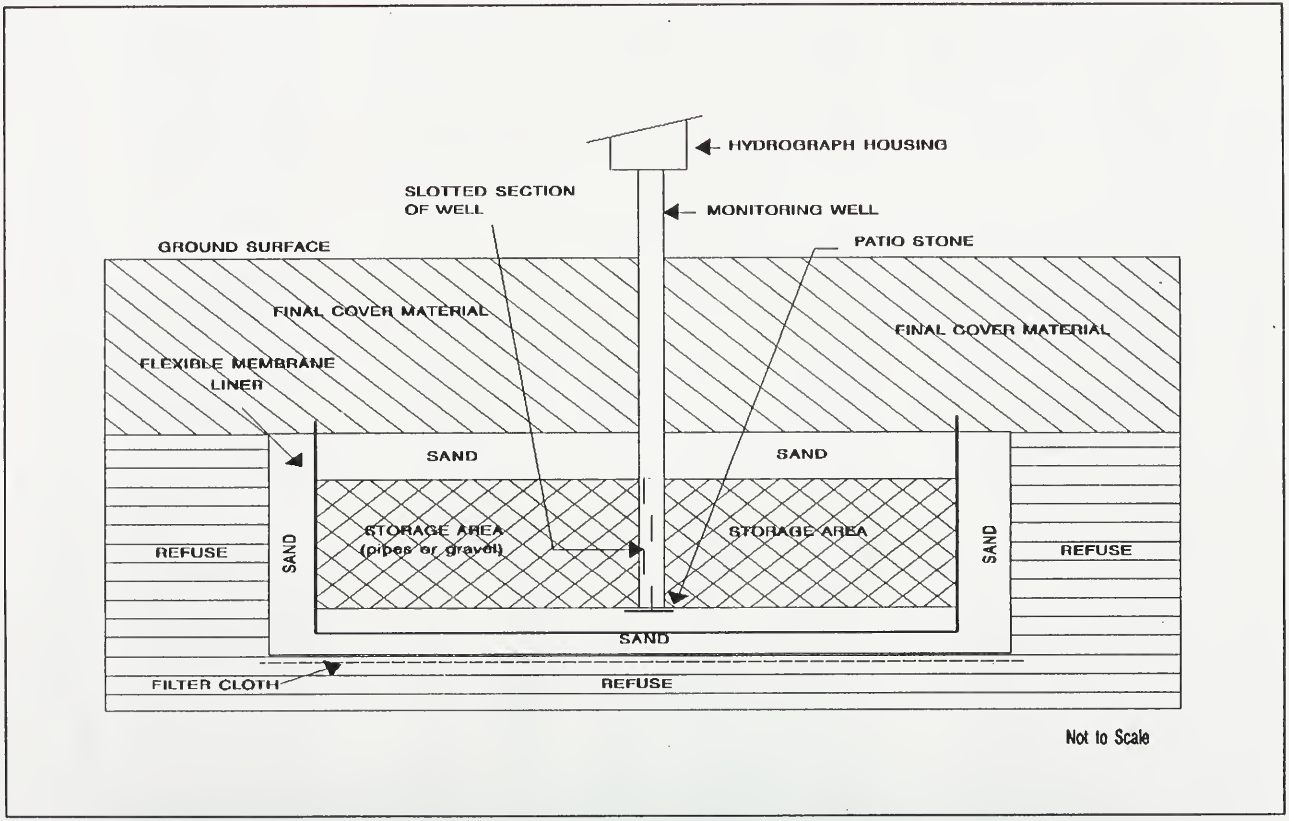


Figure 4 Basic Lysimeter Components

4.0 MONITORING RESULTS

4.1 Data Collection

Three types of measurement were used in assessing the performance of the lysimeters:

a) the monthly amount of water pumped from the lysimeters;
b) the monthly increase in water levels in the lysimeters; and
c) the continuous water levels in the lysimeters.

A general description of the methodology used to obtain the results is provided in Section 4.1.1 to Section 4.1.3. The interpretation of the data is addressed in Section 4.2. A detailed description and assessment of the procedures and the equipment that were used are provided in Appendix D and Appendix E.

4.1.1 Monthly Pump Out Data

At approximately monthly intervals each lysimeter was pumped down to a set distance above the patio stone on the base of the lysimeter and the amount of through-cover infiltration collected in the lysimeter storage zone was measured. However, as addressed in Appendix D, there are inconsistencies in the pumping method used which allowed errors of up to 35mm to result and therefore individual monthly measurements of infiltration are of questionable value. The net effect of this error is not significant as far as total annual volume of infiltration is concerned since a low calculated value for infiltration in one month results in a correspondingly high value in the next. Other errors are related to factors such as the differential settlement of the lysimeter base and the monitoring well and are more difficult to accommodate.

The amount of water pumped each month was converted to an equivalent depth of water to reflect the infiltration through the final cover. The cumulative infiltration versus time was plotted so that the slope of the infiltration curve (the rate of infiltration) could be determined and data irregularities could be easily identified.

4.1.2 Field Water Level Data

The water level in each of the monitoring wells was taken from the top of the monitoring well before and after each pump out session.

4.1.3 Continuous Water Level Recordings

Continuous water level recorders were installed on selected lysimeters. These hydrographs provide continuous records of water levels in the lysimeter storage zone (see Appendix E). These continuous water level measurements served several purposes:

a) to assist in verifying field water level measurements taken;
b) to provide information on the mechanism of infiltration; and
c) to provide verification that the lysimeters were not leaking.

4.1.4 Climate Data

The daily precipitation records were obtained from the closest Environment Canada Atmospheric Environment Service (AES) climatological stations for each site. For the Britannia site, the nearest AES station was at the Lester B. Pearson International Airport (Toronto), which is situated approximately 12 km northeast of Britannia Road Landfill. The nearest AES station for the Barrie site is the City's water pollution control plant, approximately 5 km east of the landfill site. For the Guelph site, the nearest AES station is at the University of Guelph's arboretum station, which is situated approximately 4 km to the southeast. Unfortunately, the Guelph Arboretum Station closed in August 1993. Another AES station, the Waterloo Wellington Airport, approximately 23 km southwest of the Guelph Landfill site was selected and used since September 1993.

4.2 Assessment of Results at the Britannia, Guelph and Barrie Sites

4.2.1 Monthly Pump Out Data

Figures 2, 3 and 4 present the monthly cumulative infiltration for the three sites for the period of October 1991 to October 1994 except for the lysimeters located at the Britannia site. Difficulties in the method used to pump the lysimeters at Britannia temporarily interfered with data collection (further details are provided in Appendix D and E) and therefore data from October 1991 to June 1992 have been omitted from this report. Precipitation data obtained from the various AES weather stations have also been provided on these figures. These data are also provided in tabular format in Appendix D, Tables 6,7, and 8.

As mentioned in Section 4.1.1, monthly infiltration measurement errors of up to 35mm were observed when assessing the data. During some months of low infiltration the lysimeters were not pumped. This would result in a flat line (ie. an apparent infiltration of zero) on the cumulative infiltration curves for that period and would also cause the curve to rise more steeply than it should during the next month's pump out session. Although the net effect of these errors is not significant as far as total annual volume of infiltration is concerned, attempts were made to correct the monthly pump-out volumes affected.

The monthly volume pumped and the corresponding water level change were plotted (see associated graphs on Tables E6 to E8) for each lysimeter. Since a linear relationship exists, it seemed appropriate to correct the monthly pump out data for those months affected by not pumping out the lysimeters. However, since the pump was set on the patio stone, the patio stone is the datum from which the lysimeters are being pumped and should be the datum for the water level change (ie the water level change is measured before and after a pump out on the same day). Therefore because the water level change was measured from the top of the well during a non pump out period, and was based on the change which occurred from the last pump out session, it may not correspond to the true datum (the patio stone) if differential settlement occurred. For example, if differential settlement caused the distance from the top of the monitoring well to the patio stone to change, then the water level change reported during a non-pump out session would not truly represent the amount that had infiltrated into the lysimeter. To be able to confidently correct the monthly pump out data, the height of water above the patio stone should be measured. This information would also allow for the correction of other pumping errors where the lysimeters were pumped down but not to the same datum.

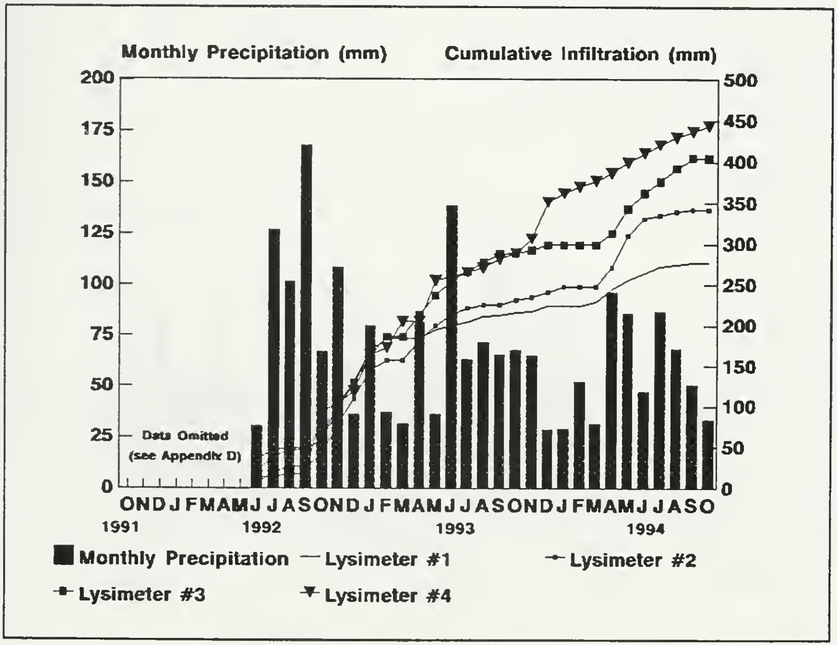


Figure 2 Britannia Lysimeters - Cumulative Infiltration (June 1992 - October 1994)

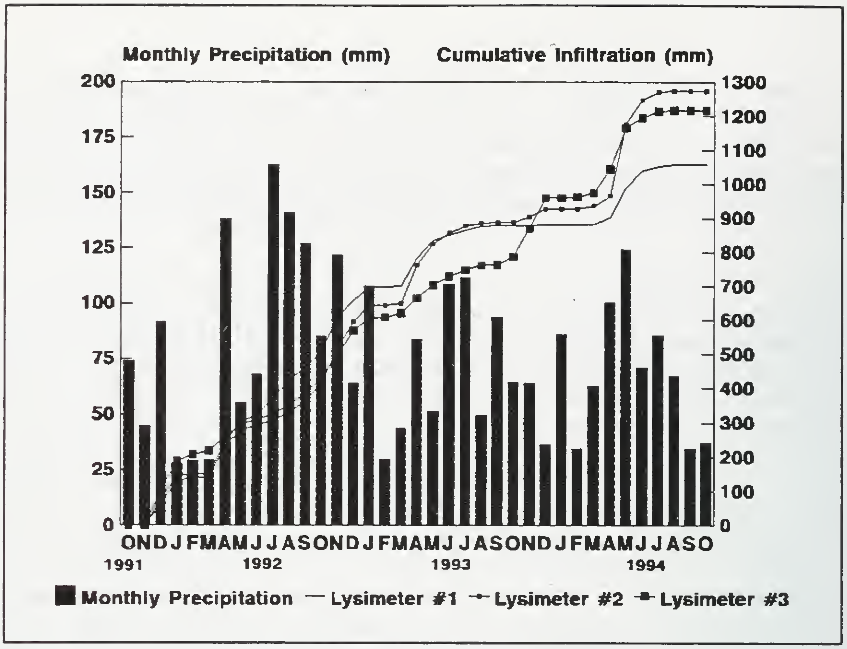


Figure 3 Guelph Lysimeters -Cumulative Infiltration
(October 1991 - October 1994)

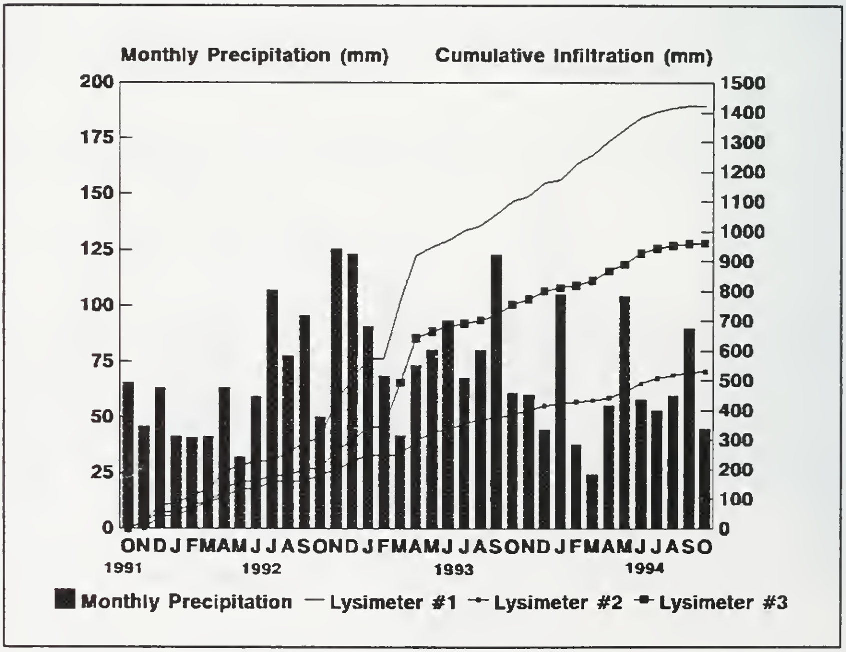


Figure 4 Barrie Lysimeters - Cumulative Infiltration
(October 1991 - October 1994)

4.2.1.1 Britannia and Guelph

The cumulative infiltration curves for all of the lysimeters at these two sites are somewhat parallel indicating similar rates of infiltration in each lysimeter. Divergence in these curves seems to be the result of individual monthly increases rather than a consistent mechanism peculiar to the individual installation.

Some of the differences between the lysimeters at the Britannia site could be attributed to the pumping problems encountered with these lysimeters (further details provided in Appendix D and E). Also, although it has not been clearly determined, it is suspected that the problems associated with barometric pressure changes may have affected the data collection efforts. During a barometric high, the water level in the lysimeters would drop below its true value. The extent that each lysimeter would react to the barometric changes varied between all four of the lysimeters. It is suspected that this behaviour is due to the relative effectiveness of the vent holes that were not plugged. As shown in Appendix D, Table 1, there were occasions where the water level measured in the lysimeters was below the datum level. Also, it was not determined whether the barometric pressure effects influenced the amount of water infiltrating into the storage zones of each lysimeter. It is recognized that landfills would be similarly affected.

As discussed in Appendix D, during two separate pumping events, the distance from the top of the monitoring well to the patio stone for the three lysimeters at the Guelph site increased. The extent of the shift varied for each of the three lysimeters. It was not determined whether the movement was due to differential settlement of the lysimeter base settling downward or the monitoring well heaving upward. It is felt that the most likely cause for these shifts is differential settlement where the base of the lysimeter drops first followed sometime later by the monitoring well (N.B.... the monitoring well is not attached to the lysimeter base but rather is cohesively connected to the cover material). In other words, there is a lag time between when the waste settles and the final cover settles in a landfill. It appeared that these shifts only temporarily interfered with the data collection in that the effects of differential settlement essentially disappeared by the next pumping session.

There is some indication of seasonal changes in infiltration rate at both sites (see Appendix F).

Some of the other differences shown in Figures 2 and 3 are not readily explained but may be a result of the vegetative cover and/or changes in the lysimeter's configuration. These are discussed below.

It was difficult to establish and/or maintain a good vegetative cover on the lysimeters at the Guelph and Britannia sites (refer to Section 3.2). The degree of vegetative cover varied on all the lysimeters throughout the data collection period, and therefore no obvious relationship between the extent of vegetative cover and infiltration could be made.

To test whether differential settlement of the refuse across the base of the lysimeter affected the integrity of these lysimeters (ie. deformation of the sides and bottom), the monthly volume pumped versus the water level change was plotted (see graphs appended to Tables E6 and E8). Deviation from a straight line relationship would be indication of lysimeter deformation and/or measurement error. The good correlation observed in the graphs appended to Tables E6 for the Guelph lysimeters 1, 2, and 3 shows that the walls and bottom have not deformed with time. At Britannia it is suspected (see graph appended to Table E8) that the scatter of points is mostly a result of the barometric effects and not a function of the lysimeter changing shape due to differential settlement of the refuse.

4.2.1.2 Barrie

The cumulative infiltration curves of the Barrie lysimeters (Figure 4) are considerably more dissimilar than those from the lysimeters at the other two sites. This dissimilarity is mostly attributed to a transient effect of a substantially higher infiltration rate into lysimeters 1 and 3 from November 1992 to April 1993 compared to lysimeter 2. The topography on and in the vicinity of these lysimeters, the textures of the surface soils and the extent of vegetative cover were examined in an unsuccessful attempt to determine the cause of these differences.

As shown in the graphs appended to Table E7, the integrity of these lysimeters does not appear to have changed substantially during the three year monitoring period.

Much like the Guelph and Britannia lysimeters, there is some indication of seasonal changes in infiltration rate at the Barrie site (see Appendix F).

4.2.2 Data From Continuous Water Level Recorders

4.2.2.1 The Mechanism of Infiltration

As noted in Appendix E, Table E.1, the continuous water level recorders on the lysimeters are able to reflect water level changes of 3 mm. Therefore major precipitation events would be reflected as sharp increases on the continuous water level hydrographs if infiltration occurred through cracks or preferred paths through the final cover. However, the hydrographs are relatively smooth and no evidence of this type of infiltration mechanism was found. This suggests, so far, that the cracks observed in the cover at the Britannia site and Guelph site do not extend through the cover and that infiltration occurs by the movement of a front of water downward. This is supported by the fact that, when the lysimeters were not properly vented, the hydrographs at the Britannia site exhibit a strong barometric effect. This barometric effect could not be present if there was free movement of air through cracks in the cover.

4.2.2.2 The Leak Integrity of the Lysimeters

Except as a result of barometric effects, the water level recorders did not show any declines in water levels in the lysimeters. This indicates that these lysimeters did not leak.

4.2.3 Preliminary Comparison of Infiltration for Guelph and Barrie

The cumulative infiltration curves for the Guelph and Barrie sites are plotted at the same scale on Figures 5 and 6 to permit a preliminary comparison to determine if the differences could be attributed to the physical characteristics at the sites. The Britannia site information has not been presented in this preliminary comparison because it is felt that the problems associated with barometric effects and other design deficiencies with the Britannia lysimeters make the results uncertain. For example, because of the lysimeter design differences, the method used to pump out the lysimeters was modified three times (see Appendix D for details). The final method may result in a low infiltration estimate. Unlike the Guelph and Barrie sites where the pump always rested on the patio stone (datum), the pump at Britannia was hung from the top of the monitoring well at a set distance from the patio stone. Differential settlement of the lysimeter base and potential separation of the patio stone from the monitoring well would not be evident and ultimately a false low infiltration estimate would result.

It is evident in Figures 5 and 6 that the overall rate of infiltration at the Barrie site is less than that at the Guelph site. It should be noted that if the slope of the cumulative curve at the Barrie site is adjusted to ignore the sharp increase in infiltration during the winter of 1992/93 there is much less divergence in these slopes and the difference between the rate of infiltration at Guelph and Barrie is more pronounced.

As mentioned in Section 3.2, the locations of the lysimeters were chosen so as to minimize any differences in slope that would affect infiltration. Table 1 compares the relative infiltration with the two gross factors at the two landfills that are considered different (final cover material and degree of vegetation) and important in affecting infiltration. Based on this comparison there does not appear to be any obvious cause which accounts for the different rates of infiltration at these sites.

Table 1. Sites with Respect to the Rating Factors that Affect Infiltration.

LANDFILL	FINAL COVER MATERIAL	DEGREE OF VEGETATION	RELATIVE MEASURED INFILTRATION
Guelph	gravelly clay 1	fair to poor 1	compared to Barrie 2
Barrie	sand 2	poor to none 2	compared to Guelph 1

1 - Less Infiltration 2 - More Infiltration

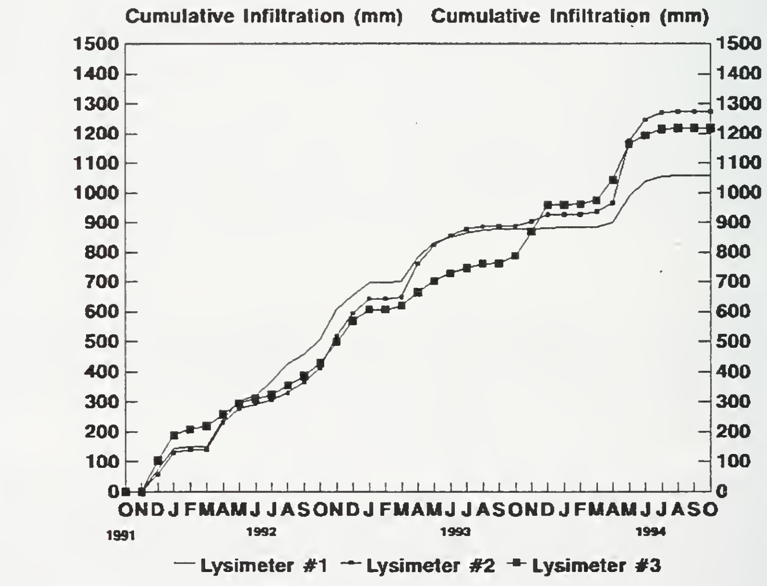


Figure 5 Guelph - For Preliminary Comparison of Infiltration Rates with Barrie Lysimeters

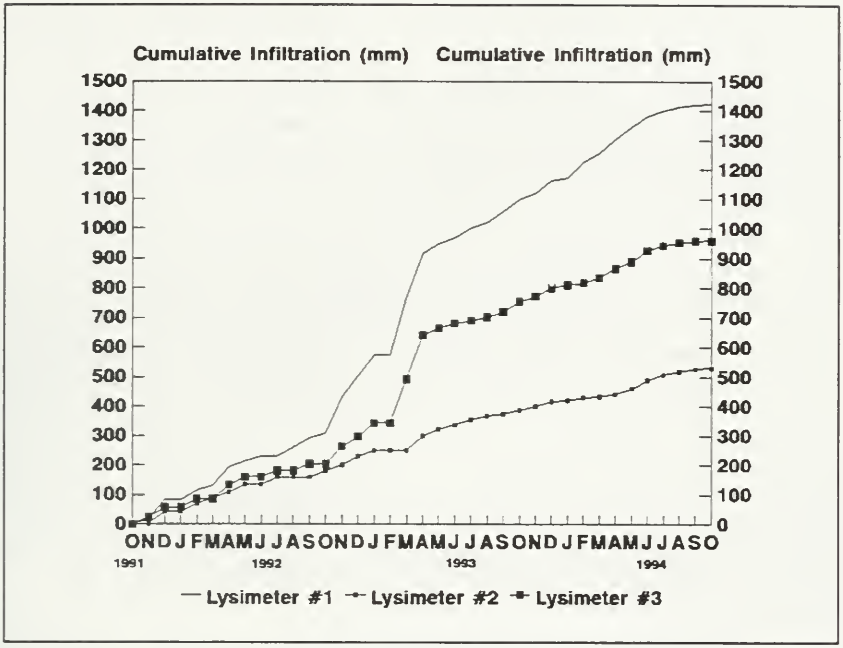


Figure 6 Barrie - For Preliminary Comparison of Infiltration Rates with Guelph Lysimeters

5.0 CONCLUSIONS

The main purpose of Phase one of this study was to develop a lysimeter design that could be used to reliably measure the infiltration that passes through landfill covers into the waste to form leachate. It is felt that the final design of the lysimeters used at the Guelph and Barrie sites probably serve this purpose, provided that the following quality control measures are taken:

a) To further assist in evaluating the accuracy of the data with respect to the impacts caused by settlement, the following should be measured and assessed during each field visit:

   1) the distance from the top of the monitoring well to the ground surface
   2) the distance from the top of the monitoring well to the base of the lysimeter

3) the height of water above the lysimeter base before and after pumping

Also, at least once a year, changes in the volume of the lysimeters should be checked for by calibration (ie. plotting the water level change vs volume pumped). Changes in the calibration curves would indicate that the lysimeter bottom and/or walls are deforming and, if large, could indicate failure.

b) To assist in interpreting the results of individual lysimeters, visual inspections should be conducted during and after storm events to look for surface depressions, ponding of water and surface preferential paths on the lysimeters

c) To ensure that barometric effects are not present and that each lysimeter is not leaking, water level recorders should be installed during the entire monitoring period

The modifications made for the Guelph and Barrie lysimeters have improved the utility and operation of the lysimeter design installed at the Britannia site. Specifically, the slots cut in the monitoring wells up to the top of the storage zone provided sufficient air and water exchange between the storage zone and monitoring well so that barometric problems evident at the Britannia site were nonexistent at the Guelph and Barrie sites. The slots also prevented the intrusion of gravel into the monitoring well.

Although there were no indications that the bentonite seals and mastic skirts installed around the outside of the monitoring wells at the Guelph and Barrie sites were insufficient, it is recommended that routine infiltrometer tests be conducted around the monitoring well to ensure that the seals are adequate to prevent preferential flow down the outside of the monitoring wells. Also, the soil in the immediate area around the outside of the monitoring wells should be mounded to promote run-off and better vegetative growth around the monitoring wells. The permeability of the final cover over the lysimeters at each landfill was identical. However, it is expected that as the landfills settle the permeability of the final cover will increase and cause a gradual increase in the annual infiltration rate. Therefore, it would be worthwhile to test the permeability of the final cover over the lysimeters with infiltrometers on a routine basis.

Since the results of this study indicate that the final cover and the lysimeter base settle independently, it is important to construct the lysimeter so that the monitoring well is not physically connected to the lysimeter base. Connecting the monitoring well to the lysimeter base may cause additional stresses on the bentonite seals and mastic skirts which could cause preferential flow paths to form down the outside of the monitoring well into the lysimeter.

Although, there was no indication during the three years and since their initial installation that any of the lysimeters were leaking or subject to complete failure, it is possible that over a longer period differential settlement across the lysimeter base would become sufficiently severe to cause failure of the lysimeters. If this project is continued, this aspect can be evaluated further. The concerns with possible changes in the lysimeter configuration could also be addressed at that time. The calibration plots appended to Tables E.6 and E.7 (monthly pump out versus monthly water level change) for Guelph and Barrie lysimeters demonstrate how little deformation of the walls or base of the lysimeters has occurred over the three year monitoring period. Although the degree of scatter shown in these plots may seem insignificant, the degree of scatter has not been fully explained and how significant these differences may become when assessing the parameters (eg. vegetation, slope etc...) in Phase two would need to be addressed.

The water pumped from some of the lysimeters was black, corrosive, smelled like leachate and contained particulates even though it had never been in direct content with the refuse. The only possible mechanism to cause such an effect would be the diffusion of gases into and out of lysimeter walls. To minimize the effect of clogging of the lysimeter storage volume over time, the lysimeter design of choice when comparing the drain tile type and the gravel type would be the large drain tile type, since it has a lower surface area, and a larger storage volume.

6.0 RECOMMENDATIONS FOR FURTHER STUDY

The objective of Phase one was to develop a lysimeter design that would provide accurate and reproducible measurement of the amount of infiltration that passes through the final cover. The results obtained from Phase one provide estimates of the rate of infiltration at each lysimeter but the causes for the differences are not sufficiently known in order to effectively evaluate and compare the parameters proposed for investigation in Phase two. Phase two should not proceed until the differences observed in Phase one can be sufficiently explained and managed.

If the differences can be explained and a quality control program is developed to address these differences, the time and effort required to manage Phase two may not be worthwhile since the amount of infiltration into a landfill can be assessed using other bulk methods (eg. measuring the volume pumped from leachate collection systems in association with the hydraulic head on the landfill liner and permeability of the landfill base). It is not known how long these lysimeters will be able to provide reliable data, and since it is the long-term infiltration rate through the maturing cover that is important with respect to the contaminating life of the landfill rather than the short term rate through an immature cover, it is not known whether the lysimeters are capable of providing the long term data required to monitor the final cover performance. Furthermore, the number of lysimeters on the top and sides of a landfill that would be needed to ensure that a representative infiltration rate was obtained might be substantial due to the unpredictable location of the heterogeneities in the cover due to differential settlement of the refuse.

7.0 REFERENCES

1. Ecologistics Limited, 1989. Erosion of Municipal Solid Waste Landfill Covers. Prepared for Waste Management Branch Ontario Ministry of the Environment.

2. Ecologistics Limited, 1989. Evaluation of Prototype Landfill Cover Lysimeters, Draft Copy. Prepared for Waste Management Branch, Ontario Ministry of the Environment.

3. Ecologistics Limited, 1990. Evaluation of Prototype Landfill Cover Lysimeters, Final Report. Prepared for Waste Management Branch, Ontario Ministry of the Environment.

4. Ecologistics Limited, 1991. Quantification of Infiltration Through Landfill Covers. Prepared for Environment Ontario.

5. Ecologistics Limited, 1992. Monitoring Infiltration Through Landfill Covers, Final Report. Prepared for Waste Management Branch, Ontario Ministry of the Environment.

6. Gartner Lee Associates Limited, 1981. Field Measurement of Infiltration Through Landfill Covers. Proposal for Consulting Services for Ontario Ministry of Environment.

7. Gartner Lee Associates Limited, 1985. Field Measurement of Infiltration Through Landfill Covers. Prepared for Ontario Ministry of Environment.

APPENDIX A

THE ORIGINAL REQUEST FOR PROPOSAL

TERMS OF REFERENCE

RAC SOLICITED PROPOSAL #161 - August 1981

FIELD MEASUREMENT OF INFILTRATION THROUGH LANDFILL COVERS

1.0 Background Information: A major source of landfill leachate is water which has infiltrated through the cover of the landfill. Increasingly, covers for domestic and hazardous waste landfills are being designed to minimize this infiltration to reduce the impact of contaminants from these facilities on the environment, in particular to ground water supplies.

Current cover designs are based in part on equations that use empirical values derived from agricultural engineering. Unfortunately, however, there are no hard field measurements of the performance of such covers on existing landfills that would demonstrate that these cover designs are valid and that infiltration is as low as predicted by the equations. This issue is important to the collection and treatment of leachate, assessing the extent and concentration of the contaminant plume, and estimating costs and design of contingency plans as required by the Ministry of the Environment.

2.0 Objective: The objective of this proposed study is to collect field measurements of the actual amount of water which infiltrates through various types of covers under various conditions. The data collected will be tested for reproducibility and compared to the results expected using the existing empirical calculations of infiltration.

3.0 Study Outline: The study is planned to be carried out within a period of 3 years.

3.1 Phase 1 - 1st Year: In this phase it is intended to develop the equipment and to complete performance tests on that equipment prior to construction of the installations to be used in Phase 2.

a) provide a preliminary description of the special field tests and experiments to be undertaken in Phase 2;
b) select and obtain access to sites to be used in Phases 1 and 2;
c) design selection and equipment specification;
d) after approval of the design and location of the test sites has been given in writing by the Crown construction of test infiltration collection systems for performance testing;
e) bring infiltration collection systems to field capacity or into a conditions such that useful measurements can be obtained;
f) performance testing;
g) performance assessment of test infiltration collection systems.

3.2 Phase 2 - 2nd and 3rd Years: This phase will not proceed until the design of the test infiltration systems has been accepted by the Crown to perform as intended and the sites proposed for Phase 2 have been approved in writing by the Crown.

1. construct additional infiltration collection systems and conduct special field tests

and experiments designed to evaluate the various parameters associated with landfill cover design

2. continue monitoring at test installations

4.0 Statement of Work

4.1 The successful Consultant is to provide a discussion of landfill sites which may be suitable for the establishment of a testing area and make recommendations for site selection criteria to be utilized.

4.2 The successful consultant will be asked to arrange for access and permission to construct infiltration collection systems at a selected test site or sites, to make the necessary arrangements are required to complete the objective of the study and is to provide an estimate of associated costs.

4.3. The suggested lysimeter design for collecting infiltration is a sheet lysimeter which would drain to a container where the water would be collected and volume monitored so as to reflect individual events, perhaps on a continuing basis. Soil moisture measurements by means of a neutron probe and reference soil samples may be desirable, at least throughout short term experiments. Rain gauges and ancillary equipment to collect climate data required for the measurement of precipitation, evaporation, temperature and humidity may be considered. Whatever system is developed during this study and is constructed must be brought to field capacity or into a condition such that useful measurements can be obtained within the first year of this study.

4.4 The successful consultant is asked to review the equipment suitability for obtaining consistently reproducible data and to include in his proposal any alternatives in design and to prepare costs of construction and related equipment purchases or leases.

4.5 The successful consultant should consider designing and performing tests or experiments to demonstrate the following relationships:

a) infiltration and physical characteristics of the cover;
b) infiltration and the final grooming of cover;
c) infiltration and various soil water conditions;
d) infiltration and cover slope; and,
e) propose other relationships as may be considered necessary.

4.6 The successful consultant is to review and present all data collected and determine the accuracy and reproducibility. The data are to be compared to the results expected using the existing empirical calculation methods for determining infiltration into landfills. The consultant should be prepared to suggest reasons for any differences.

INFORMATION TO CONSULTANTS

RAC SOLICITED PROPOSAL #161

FIELD MEASUREMENT OF INFILTRATION THROUGH LANDFILL COVERS

1. Description of Work: The Consultant or team of consultants shall provide expertise, labour and equipment in the selection of a design for an infiltration collection system, construction, design testing, data collection, data verification, analysis, and evaluation of infiltration through various landfill covers under various conditions.

2. Project Management: The study shall be managed by the Liaison Officer of the Study appointed by Research Advisory Committee. The consultant or team of consultants shall be expected to carry out and carry to completion the study expeditiously and within a three-year period. The successful applicant shall act as an independent consultant and not as a servant or agent of the Ministry of the Environment.

3. Contract Costs: Consultants are advised that the total cost of the study is estimated to be $100,000 of which a maximum of $25,000 is available in the fiscal year 1981.

4. Qualifications: The consultant shall be capable of undertaking the study, data analysis and report preparation. The consultant shall be proficient and current in the fields addressed: solid waste disposal, landfill design, and flow in the unsaturated zone, and be able to relate the objectives of this study to the current state of the art. The consultant shall be competent to design, construct and test infiltration collection systems to be used in this study.

   The consultant maybe in fact a team of consultants, a firm or company.

   The consultant shall appoint or have on staff both a fully qualified agricultural engineer and a fully qualified hydrogeologist who will review and incorporate into the study relevant discussion and aspects of the agricultural engineering and hydrogeological sciences.

5. Delivery and Opening of Proposals: Proposals sealed in the envelopes provided, will be received by the Liaison Officer, Chief of the Ground Water Protection Unit, Hydrology and Monitoring Section, Water Resources Branch, Ministry of Environment, 1 St. Clair Avenue West, Toronto, M4V 1P5, until 3:00 p.m., Toronto time, on

   September 3, 1981

6. Preparation of Proposal: Each Request for Proposal Document shall include the following:

   1. Terms of Reference
   2. Information to Consultants

   A consultant may withdraw or submit a further proposal any time up until the official closing time. Letters of withdrawal and the last proposal received shall supersede and invalidate all proposals or sections of proposals previously submitted.

7. Proposal Content: Proposals should be brief, direct, and specific in language and in format. Each proposal shall contain the following information pertinent to the study:

a) Statement of Work: A description of: the criteria which the consultant plans to use in the design and construction of an infiltration collection system; the methods the consultant intends to use to gather, verify and evaluate data required by this study. This description should not be more than 5 single-spaced pages in length.

b) Project Plan: A schedule indicating the individual tasks required to complete the work showing staff and resources, estimated man-day requirements for each task, and defining the critical path required to complete the study including interim and final reports.

c) Schedule of Items and Prices: An itemized breakdown of the costs for each phase, as described in the attached Terms of Reference, prices, estimated living expenses, phone calls, etc. and any other associated study costs. Equipment is to be identified and itemized costs shall be included.

The consultant shall be responsible for obtaining, at his own expense, all things necessary that are required to perform the study including any laboratory facilities.

The consultant shall provide a contingency allowance which will not be used throughout the study without the written permission of the Research Advisory Committee.

All salaries and expenses related to personnel assigned to the project shall be subject to approval as being reasonable. Amounts not in excess of those equivalent to the current A.P.E.O. schedule of salaries and fees, or amendments thereto, with any necessary changes to reflect rates of remuneration for different jobs, shall be accepted as reasonable.

d) Statement of Qualifications: A listing of the Consultant's experience in similar work indicating the client, description of the contract, year completed and the value of the work. Also to be included in the proposal is a list of the senior supervisory staff, hydrogeologists, agricultural engineers, subcontractors and any technical staff to be associated directly with this project providing a description of team structure, accountabilities and curriculum vitae of the personnel listed.

e) Reports: The consultant shall provide oral progress reports from time to time at the request of the Liaison Officer. Progress reports in triplicate shall be submitted to the Liaison Officer every month or as requested.

The study requires the submission of a draft final report with five copies.

The final report shall be prepared based on the draft report and the comments from the Liaison Officer. Ten copies of the final report, shall be submitted to the Liaison Officer.

The material is to be presented in SI units according to the Ministry of the Environment Metrification Guidelines for Consulting Engineers, February 1977. Imperial units may be included in parenthesis.

8. Acceptance or Rejection of Proposals: After the closing date, the proposals shall be checked and analyzed by the Liaison Officer and a proposal recommended for acceptance to the Research Advisory Committee. Proposals which are incomplete, conditional, illegible or obscure or contain irregularities of any may be rejected. The Crown reserves the right to reject any or all proposals as the interest of the Ministry of the Environment, Research Advisory Committee may require without stating reasons therefore and the lowest or any proposal will not necessarily be accepted.

   The recommendation of a proposal for acceptance does not constitute acceptance of the proposal. Only the issuing of a formal purchase order will do so.

9. Award of Contract and Conditions of Work: If a proposal that has been recommended is accepted, a successful consultant (the "Contractor") will be asked to enter into an agreement with Her Majesty the Queen in Right of Ontario as represented by the Ministry of the Environment (the "Crown"). A formal purchase order will be issued and delivered to the successful consultant and such purchase order will incorporate by reference the proposal accepted and together with the Request for Proposal documents will constitute a "contract". The successful consultant on receipt of a Purchase Order from the Crown shall issue a letter accepting the Purchase Order and its conditions.

10. Payment: Payments shall be based on prices in the schedule of items and prices provided by the Consultant in his proposal.

    Progress payments shall be paid monthly after presentation of invoices supported by receipts or other documents to establish that the invoice is for amounts reasonably incurred or earned in connection with the study.

11. Books and Records: The Ministry of the Environment shall have the right to inspect or audit any records of the Consultant or anyone working directly or indirectly for the consultant for the purposes of the study to determine that any amount is reasonable and has been properly incurred for the purpose of the study.

12. Equipment: All capital equipment purchased by the consultant with project monies is the property of the Crown and will be returned to the Ministry of the Environment at the completion of the project.

13. Subletting: The consultant shall keep the work under his personal control and shall not assign, transfer or sublet any portion without first obtaining the written consent of the Ministry. The consent of the Ministry to any such assignment, transfer or subletting shall not however relieve the consultant of any responsibility for proper commencement, execution and completion of the work according to the terms and conditions of the purchase order. If the Ministry consents to any such assignment, transfer or subletting the consultant shall either in person or through an accredited agent receive all notices, communications, orders, instructions, or legal service, as if her were performing the work with his own plant and with his own personnel.

14. Consultant's Risk: The Ministry of the Environment will not be responsible for any damage or loss to the Consultant's vehicles or any other equipment owned or leased by the consultant.

15. Insurances: The consultant shall indemnify and save harmless the Ministry from and against all claims, demands, loss, costs, damages, actions, suits or other proceedings by whomsoever made, brought or prosecuted in any manner based upon, occasioned by or attributable to any such damage, injury or infringement.

The consultant will provide on request, on forms supplied by the Ministry evidence of general liability insurance having a limit of not less than $500,000 inclusive and automobile liability insurance having a limit of not less than $500,00 inclusive, such insurance to name the Crown as an additional insured thereunder and to remain in full force for the term of the project.

The Consultant shall carry adequate public liability and property damage insurance and all employees engaged in the above work shall be covered by insurance in the regular manner as prescribed by the Workman's Compensation Board.

16. Safety: The consultant shall be responsible for the strict observance of all mandatory safety regulations. Any damage incurred in the execution of the above work shall immediately be made good by the consultant without cost to the Ministry.

The above work shall comply with the statutory regulations and requirements of all persons or bodies having jurisdiction.

On completion, the site or sites shall be left clean and tidy and all waste materials removed by the Consultant except where otherwise directed.

The above work shall be completed to the satisfaction of the Ministry of the Environment.

17. Performance Bond: Upon request of the Ministry of the Environment, the consultant shall obtain a Performance Bond. The consultant shall be reimbursed for the cost of the Bond by the Ministry of the Environment.

18. Termination: Crown at its discretion and dependent on the performance of the consultant and the availability of funds and the results of the work may terminate the contract by giving written notice of such termination to the consultant. The Ministry shall use its best efforts to give notice of termination promptly and to advise the consultant in the event the giving of notice of termination becomes likely.

The Crown may cancel the contract at any time and its only obligation shall be to pay the consultant for all work done to the date of termination and for any expenses which the consultant remains legally obliged to pay in connection with the study.

19. Ministry Property: The information, materials, documents, data, working papers and the like which relate to this Project and which the consultant may acquire, possess or generate are the property of the Crown and shall be surrendered to the Ministry or disposed of at the direction of the Liaison Officer upon the conclusion of the project or termination of the contract.

All data and information obtained and all reports prepared in the course of the project are the property of the Crown and may be published or otherwise used in whole or in part, by the Crown, the Crown shall acknowledge in any such publication, the role played in the project by the Consultant. The Crown shall grant permission to the consultant to publish any report prepared in the course of the project and submitted to the Liaison Officer, provided that the consultant, in any such publication, acknowledges the role of the Crown in causing the report to be prepared and has permission from the Crown to release the report as public information. Any report prepared for submission to the Crown or for publication by the consultant shall bear, with the appropriate date, the statement: "(c) 198_ Her Majesty the Queen in Right of Ontario as represented by the Minister of the Environment".

ADDENDUM NO. 1

RAC SOLICITED PROPOSAL #161
FIELD MEASUREMENT OF INFILTRATION THROUGH LANDFILL COVERS

The following amendments are hereby made in this set of request for proposal documents.

1. Information to Consultants

In Section 5, paragraph 1, line 7, delete the line and substitute September 24, 1981, therefor:

Ground Water Protection Unit
Hydrology and Monitoring Section
Water Resources Branch
1 St. Clair Avenue. West
Toronto, Ontario
M4V 1P5

August 26, 1981

ADDENDUM NO. 2

RAC SOLICITED PROPOSAL #161
FIELD MEASUREMENT OF INFILTRATION THROUGH LANDFILL COVERS

The following amendments are hereby made in this set of Request for Proposal Documents.

1. Information to Consultants

In Section 5, Paragraph 1, delete the line and substitute October 1, 1981, therefor.

Ground Water Protection Unit
Hydrology and Monitoring Section
Water Resources Branch
1 St. Clair Avenue. West
Toronto, Ontario
M4V 1P5

Date: September 18, 1981

APPENDIX B

LYSIMETER DESIGNS

APPENDIX B.1

Excerpts from a 1985 Gartner Lee Associates Limited report titled " Field Measurement of Infiltration Through Landfill Covers", pages 8 to 14

B.1 GARTNER LEE LYSIMETER DESIGN AND CONSTRUCTION

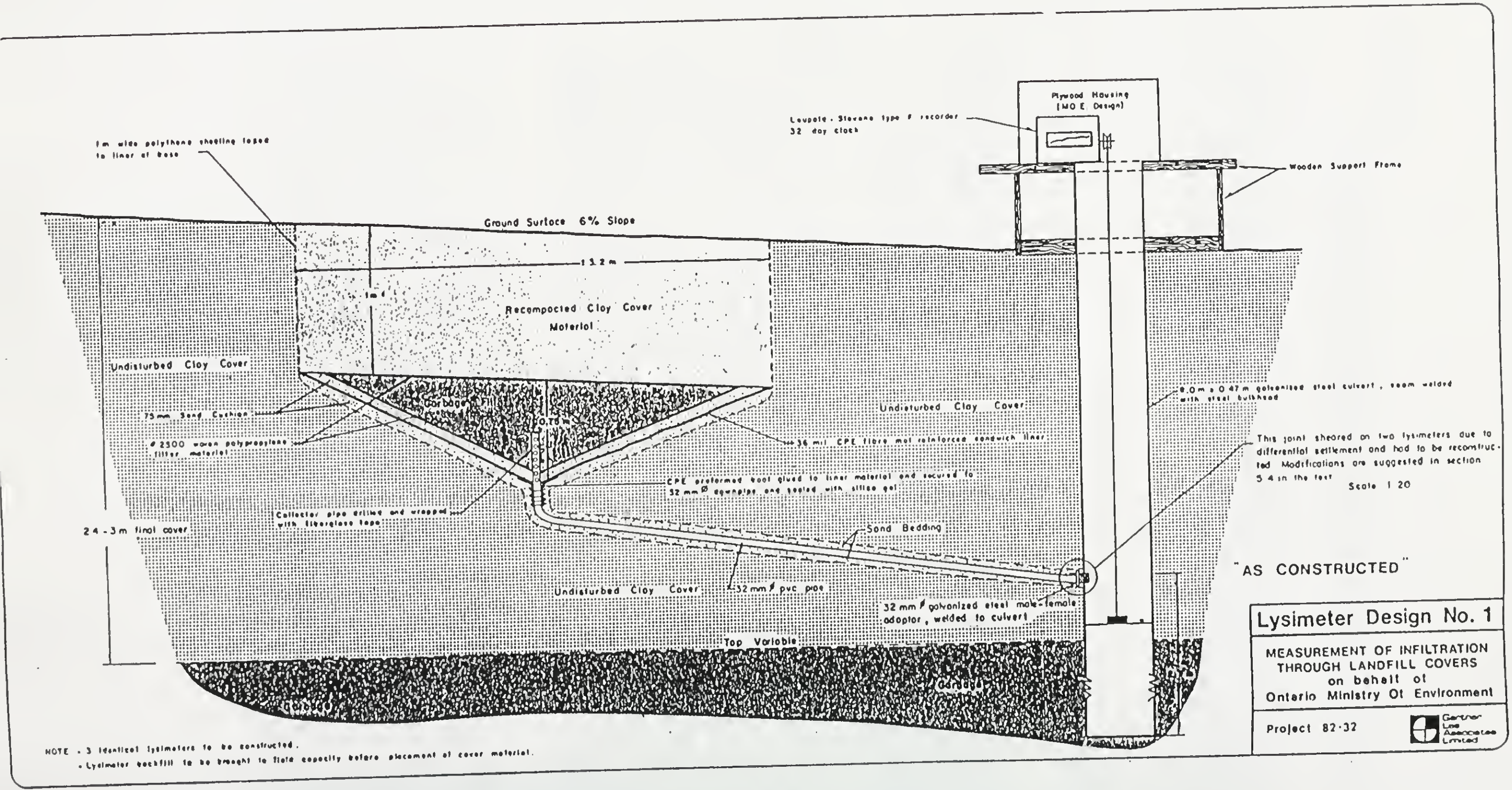
Originally, only one lysimeter design was proposed. This design was of a relatively sophisticated data acquisition type that included a storage well and automatic data recording mode. Subsequent to undertaking the project, MOE staff suggested that a much simpler type of sheet lysimeter should also be constructed and the results compared to those from the more sophisticated design. Details of each design now follow:

LYSIMETER DESIGN #1

Details of design No. 1 are presented on Figure 2. In order to check the reproducibility of results, three identical lysimeters were constructed. Since clay cover is placed over the garbage, differential settlement of the landfill cover will occur as the underlying garbage decomposes. This leads to a secondary fracture permeability developing in the clay cover, which in this setting, can ultimately become the major factor controlling infiltration. The lysimeters were therefore designed to encompass a fairly large surface area, 10 m^2, in order to be as representative of the cover as possible.

The design of each lysimeter basically consists of an infiltration capture unit from which the water is directed to a storage well equipped with an automatic water level recorder. The original design called for the lysimeter to be constructed below the cover material, within the garbage. However, at this particular site, the thickness of the final clay cover was significantly greater than anticipated. As a consequence, the lysimeter was constructed within the cover material, with only the collection well protruding into the underlying garbage. The collection well, consisting of a 6.0 x 0.47 m diameter seam welded, asphalt coated galvanized steel hel-cor pipe with steel bulkhead, was installed first in late October 1982. Details of the well are provided in the Appendix. The pipe was installed by means of a backhoe excavator because it was not possible to penetrate the garbage with a large diameter Stirling auger drill rig, as was originally planned. The size of the excavation required in order to install the collection well and subsequent backfilling, did create some differential settlement problems later on.

The next stage was to excavate for the lysimeter, which was again accomplished with a backhoe. The clay cover was excavated from a 3.2 x 3.2 m area, to a depth of approximately 1 m. This was followed by excavation of the inverted cone shape of the lysimeter. The 32 mm diameter PVC collector pipe running from the base of the lysimeter to the collector well was then placed on a sand bed and covered with sand and the trench backfilled with clay material. The connection into the collector well was made via a 32 mm diameter threaded female stub which had been welded into the well. The first time the trench was backfilled, the connection at two of the wells severed due to differential settlement between the well and the pipe. The trench was re-excavated down to the base of the collector well and the material recompacted around the well. The pipe was re-laid on a thicker sand bed and the trench backfilled again.


1m wide polythene sheeting taped to liner at base
Ground Surface 6% Slope
13.2 m
1m
Recompacted Clay Cover Material
Undisturbed Clay Cover
75mm Sand Cushion
#2300 woven polypropylene filter material
Garbage Fill
0.75 m
Collector pipe drilled and wrapped with fiberglass tape
2.4 - 3m final cover
36 mil CPE fibre mat reinforced sandwich liner
CPE preformed boot glued to liner material and secured to 32 mm Ø downpipe and sealed with silica gel
Sand Bedding
Undisturbed Clay Cover
32 mm Ø pvc pipe
32 mm Ø galvanized steel male-female adaptor, welded to culvert
Top Variable
Garbage
Plywood Housing (M.O.E. Design)
Leupold - Stevens type F recorder 32 day clock
Wooden Support Frame
Undisturbed Clay Cover
9.0m x 0.47 m galvanized steel culvert, seam welded with steel bulkhead
This joint sheared on two lysimeters due to differential settlement and had to be reconstructed. Modifications are suggested in section 5.4 in the text
Scale 1:20
"AS CONSTRUCTED"
Lysimeter Design No. 1
MEASUREMENT OF INFILTRATION THROUGH LANDFILL COVERS on behalf of Ontario Ministry Of Environment
Project 82-32
Gartner Lee Associates Limited
NOTE - 3 identical lysimeters to be constructed.
- Lysimeter backfill to be brought to field capacity before placement of cover material.

Source: Gartner Lee Associates Limited, March 1985. page 9

Figure 2 Lysimeter Design Number 1

The actual lysimeter was constructed using a 36 mil CPE[*] fibre mat reinforced sandwich liner material placed on a sand bed. The connection to the collector well was made using a chlorinated polyethylene preformed boot which was glued to the liner material and secured to the downpipe using screw clamps. The connection was then made watertight using silicone caulking. A 75 mm thick sand cushion was placed on the liner material followed by a protective filter made from #2300 woven polypropylene material. This was used as a precaution against accidental puncturing of the liner as the lysimeter was filled with garbage. Garbage was used as the fill material in order to reflect as close as possible, the actual situation of garbage beneath a clay cover. The filter cloth material was placed over the top of the garbage fill, to prevent downward migration of fines from the clay cover into the lysimeter. As construction of the three lysimeters was done concurrently, the excavations were open for in excess of one week. Several rainfall events occurred during this time which was assumed to bring the lysimeter backfill to field capacity.

Prior to replacing the clay cover material, polyethylene sheeting was placed around the full height of the excavation and attached to the lysimeter liner to prevent horizontal ingress of water through the sides of the excavation. In this manner, only vertical infiltration down through the clay cover could enter the lysimeter installations. The clay cover was then re-compacted into the excavation, in lifts of 150 mm using a gas-driven plate compactor. In-situ density tests, which were performed on the clay cover material prior to construction in order to determine the existing conditions indicated an average density of 2 t/m^3. The clay cover was replaced to the existing grade. The slope of the surface at lysimeters 1 and 2 was approximately 6%. The ground surface at lysimeter #3 had a slope of about 10%.

The final stage of the construction was to install the Leupold-Stevens type F continuous chart water level recorders. The recorder housings were built to MOE specifications and supported on a wooden framework which also served as a surface support system for the collector wells. The chart recorders, which are equipped with a battery operated, 32 day clock, have been operational since mid-March 1983. Since it had been necessary to pump out water from the collection wells on several occasions, both during and after construction, it was assumed that the installations could be considered to be at field capacity by the time the recorders were operative. Removal of water from the storage wells is accomplished by means of a contractors sump pump, equipped with a 6 m intake line. The ground surface at the installations remained without topsoil until the area was seeded in early September.

The volume of storage available in the well, up to the level of the discharge pipe from the lysimeter, is equal to 0.47 m^3. This is equivalent to a total infiltration of 47 mm over the 10 m^2 surface area of the lysimeter installation. The sensitivity of the installation is such that an infiltration of 1 mm into the lysimeter should produce a water level rise of 57.6 mm in the storage well, assuming 100% efficiency of the instrument. The automatic water level recorders have a working range of approximately 3 m. The charts are calibrated in increments of 30.5 mm which represent a height of 0.30 m in the well. The minimum water level increase in the well which can be identified on the chart is about 5 mm±. This is equivalent to an infiltration of approximately 0.09 mm of water applied over the surface area of the lysimeter.

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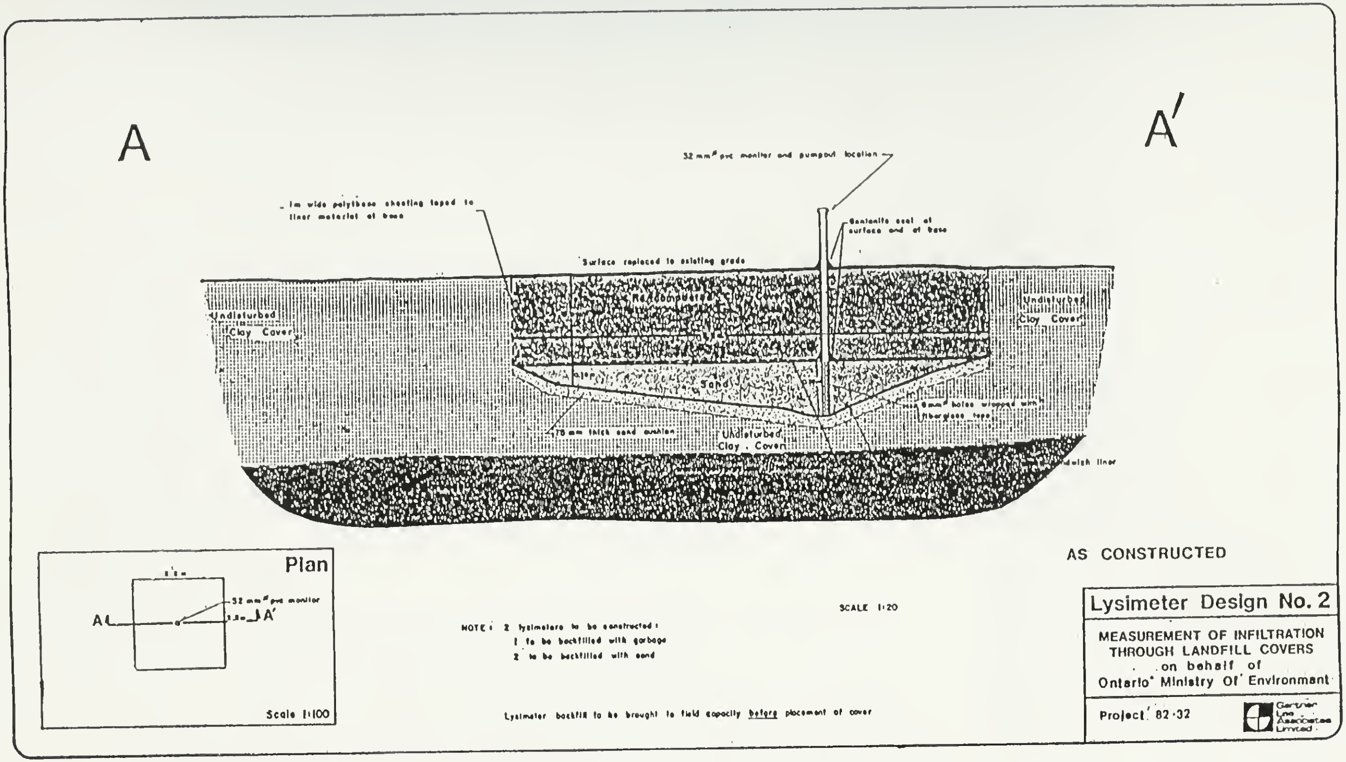
[*] CPE = Chlorinated Polyethylene

LYSIMETER DESIGN #2

Details of lysimeter design No. 2 are presented on Figure 3. The design consists of a simple sheet lysimeter equipped with a 32 mm diameter PVC monitoring and pump out pipe. There is no storage well nor automatic water level recording mode with this design.

Two lysimeters, again 3.2 x 3.2 m surface area, were constructed, one using a sand fill and one using a garbage fill. The design consists of a 36 mil CPE fibre mat reinforced sandwich liner placed on a sand cushion. The lysimeter is approximately 0.4 m deep at the lowest point beneath the clay cover. Woven polypropylene filter material #2300 was again used to prevent movement of fines from the clay cover above the lysimeter was reduced to approximately 0.6 m. Polythene sheeting was again placed around the sides of the excavation prior to backfilling. The clay cover was recompacted in the same manner as before.

The approximate volume of this lysimeter, below the soil cover, is 1.9± m^3. If the effective porosity of the lysimeter backfill is assumed to range between 0.2 - 0.3, then the volume of voids which is available for storage of infiltration will vary between about 0.4-0.6 m^3. This volume is equivalent to a total infiltration of between 40 - 60 mm (1.5 - 2.5 inches). In order to obtain accurate measurements of infiltration, these lysimeters would require a significant amount of calibration.


A
A′
32 mm⌀ pvc monitor and pumpout location
1m wide polythene sheeting taped to liner material at base
Bentonite seal at surface and at base
Surface replaced to existing grade
Undisturbed Clay Cover
Recompacted Clay Cover
Sand
6mm⌀ holes wrapped with fiberglass tape
70 mm thick sand cushion
Undisturbed Clay Cover
liner
Plan
A
A′
32 mm⌀ pvc monitor
Scale 1:100
NOTE: 2 lysimeters to be constructed:
1 to be backfilled with garbage
2 to be backfilled with sand
SCALE 1:20
Lysimeter backfill to be brought to field capacity before placement of cover
AS CONSTRUCTED
Lysimeter Design No. 2
MEASUREMENT OF INFILTRATION THROUGH LANDFILL COVERS on behalf of Ontario Ministry Of Environment
Project 82-32
Gartner Lee Associates Limited

Source: Gartner Lee Associates Limited, March 1985, page 15

Figure 3 Lysimeter Design Number 2

APPENDIX B.2

Excerpts from a 1989 Ecologistics Limited report titled "Erosion of Municipal Solid Waste Landfill Covers", pages 91 to 94

B.2 BRITANNIA ROAD LANDFILL LYSIMETER DESIGN AND CONSTRUCTION

Construction of the lysimeters began at 8:00 am on August 10, 1987 at Britannia Road Landfill, located at Britannia Road and Second Line in Mississauga.

The area designated for the six lysimeters is in the southwest corner of the landfill. The 120 metre strip of land is situated in a predominantly north-south direction and has a very gentle slope to the west. Construction began by excavating six holes 4.6 metres x 4.6 metres x 1.5 metres with a backhoe. This part of the project took approximately 2.5 days to finish. Each hole was surveyed using a survey transit to ensure that the bottom was level. The clay cover that was excavated was piled on one side of the excavation and the excavated solid waste was piled separately on another side. The solid waste was removed the next day and landfilled. The piled clay was used for cover material over the lysimeters.

Each lysimeter was positioned so that its northeast corner was several feet from a survey stake. Each survey stake had co-ordinates marked on it from which contours can be obtained. The survey stakes are approximately 20 metres apart, therefore, the distance separating they lysimeters is approximately 15 metres (See Figure 1).

After the lysimeter pits were finished, construction of each lysimeter began by placing a 4.6 metre x 4.6 metre sheet of filter cloth on the bottom of the pit and covering this with six inches of sand. The sand was compacted by the backhoe and by foot. Originally, two tampers were called in to tamp the sand layer but the tamper displaced the sand rather than compacting it, therefore, they were not used. Once compacted, the sand layer was checked to ensure it had a level surface.

The flexible membrane liner (93 mil thickness) was unrolled in the pit, and centered. It was received from the manufacturer pre-formed in the shape of a box with dimensions 3.1 metres x 3.1 metres x .91 metres. One wooden stake was driven into the sand at each corner of the liner. Two-by-fours were used to construct the frame from which the liner would hang. Three metre lengths of two-by-fours were nailed to the wooden stakes .91 metres above the top of the sand. The entire wooden frame was checked to ensure that the lysimeter would be completely level.

The top of the liner was pulled up to the wooden frame .91 metres off the bottom and attached securely by 1.25 inch roofing nails. The liner was positioned on the frame loosely to prevent tearing due to differential settlement of the garbage below.

Once the liner was in place, a 15 cm layer of sand was placed inside the liner. The area outside the lysimeter was filled simultaneously with the interior to ensure the liner walls maintain a vertical position. Once the sand layer was completed to the appropriate thickness and levelled off, 1.5 inch piece of patio stone .61 metres x .61 metres was centrally placed 7.5 centimetres deep. The patio stone was then checked to ensure it was level.

A piece of filter cloth 3.4 metres x 3.4 metres was placed over the sand layer and the patio stone. The 35.6 centimetre diameter monitoring well was centred on the patio stone above the filter cloth. The monitoring well was checked with a level to ensure it was perfectly vertical.

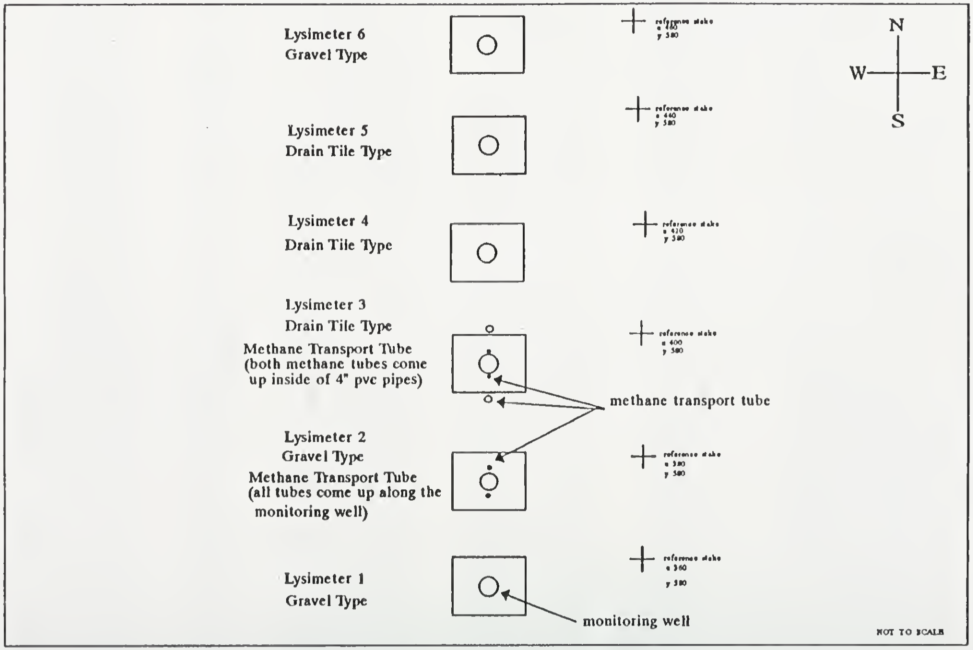

Lysimeter 6
Gravel Type
Lysimeter 5
Drain Tile Type
Lysimeter 4
Drain Tile Type
Lysimeter 3
Drain Tile Type
Methane Transport Tube (both methane tubes come up inside of 4" pvc pipes)
Lysimeter 2
Gravel Type
Methane Transport Tube (all tubes come up along the monitoring well)
Lysimeter 1
Gravel Type
reference stake x 460 y 580
reference stake x 440 y 580
reference stake x 420 y 580
reference stake x 400 y 580
reference stake x 380 y 580
reference stake x 360 y 580
methane transport tube
monitoring well
N
W
E
S
NOT TO SCALE

Figure 1 Britannia Road Landfill Layout

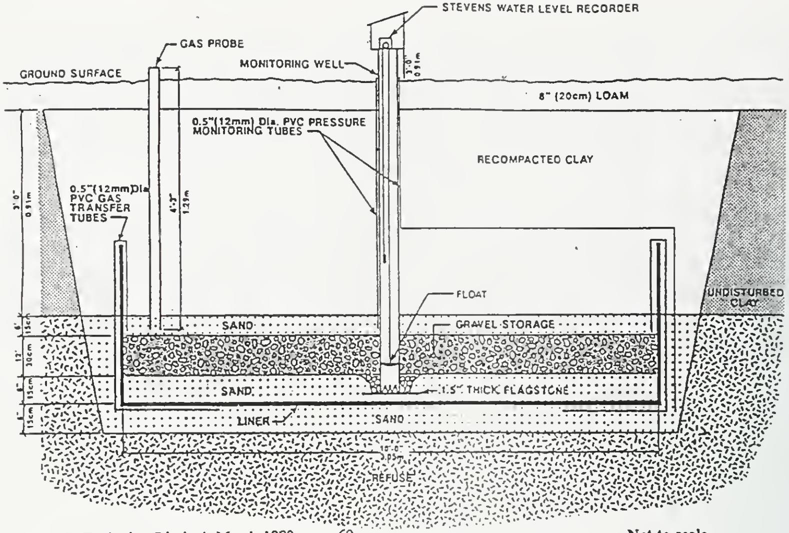
At this point in the construction the remaining material that went into the lysimeter depended on the lysimeter type. The two types of lysimeters installed were gravel and drain tile. The gravel lysimeter required 30 cm of gravel to be placed within the lysimeter. The drain tile type required two layers of slotted drain tiles (10.2 centimetre diameter) to be placed horizontally within the lysimeter. The second "layer" of tiles were placed 90 degrees to the first layer. The space between the drain tiles and the monitoring well was filled in with gravel up to the second layer of tiles.

Filter cloth was placed over the gravel or drain tiles depending on the type of lysimeter installed. A slit was cut in the filter cloth to allow it to slip over the monitoring well. A 15 cm sand layer was placed on top of the filter cloth and compacted by foot. The top of this sand layer is approximately .32 to .61 metres below surface. The area chosen for the lysimeter construction is receiving an additional .61 to .91 metres of clay cover. This will bring the total thickness of cover material being monitored by the lysimeters to approximately 1.2 metres.

The recompacted clay is placed into the lysimeters in approximately 15 to 20 centimetre lifts which is then compacted using a pneumatic vibrator attached to the backhoe. Each lysimeter was tested for compaction using a nuclear densitometer. The results of compaction ranged from 95 to 100% standard proctor density. Bentonite was placed around the monitoring well in both lifts to prevent vertical migration of water along the sides of the well.

The two lysimeter types installed at the Britannia Road Landfill site can be distinguished from one another by referring to each by the material used for the storage zone. More specifically, they can be referred to as the "gravel type lysimeter" or the "drain tile type lysimeter". As illustrated in Figure 2.2 and 2.3 the lysimeter types are virtually identical in design with the exception of the depth and material used for storage zones, that being, 30 cm of gravel and 21 cm of drain tile, respectively. With the drain tile storage zone being approximately 9 cm lower than the gravel storage zone, the additional depth is accounted for by placing a greater depth of sand over the drain tile type lysimeter than was found in the gravel type.

Gravel Type Lysimeter Cross-Section

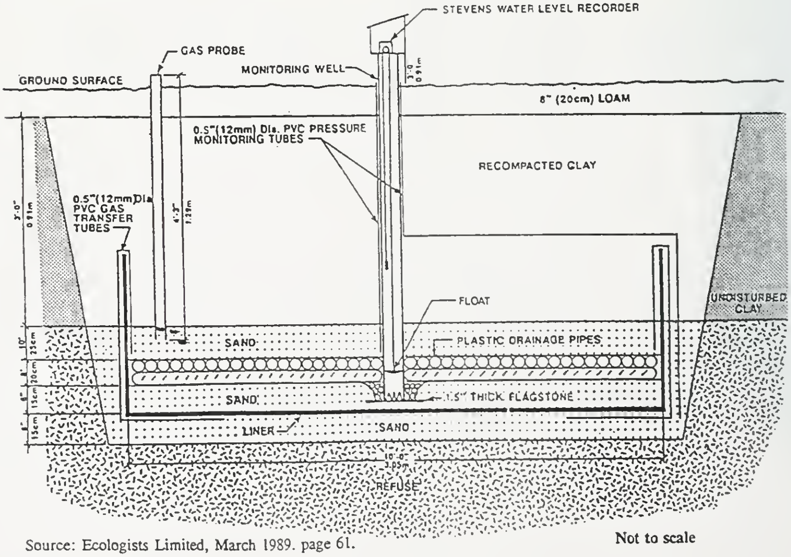


Source: Ecologists Limited, March 1989. page 60.

Not to scale

Figure 2.2 The Lysimeter design of lysimeters 1, 2 and 6 at the Britannia Landfill

Drain Tile Type Lysimeter Cross-Section



Source: Ecologists Limited, March 1989. page 61.

Not to scale

Figure 2.3 The Lysimeter design of lysimeters 3, 4 and 5 at the Britannia Landfill

APPENDIX B.3

Excerpts from a 1991 Ecologistics Limited report titled " Quantification of Infiltration Through Landfill Covers", pages 8, and A1 to A6

B.3 GUELPH AND BARRIE LYSIMETER DESIGN AND CONSTRUCTION

Installation of the lysimeters at both sites was undertaken in September 1989. A rigid protocol was followed during construction. A summary account of the installation steps is provided here. Installation began by excavating a 4 m x 4 m hole in the landfill cap. The depth of the hole was dictated by the final cover depth. This was due to the fact that the lysimeters were installed in the underlying garbage to a depth which resulted in the side walls of the lysimeter extending only 0.3 m (1 foot) into the overlying cap. As the cap was excavated, densities of the cap were taken at 15 cm (6 inch) intervals using a CPN Corporation, model MC-1, moisture/density gauge. These densities were used as a reference for restoring the cap as close as possible to its original condition when replacing the cap material over the lysimeter. All pertinent elevations associated with the lysimeters such as the elevation of the patio stone at the base of the well were recorded and references to a known benchmark.

Water level recorders including the shelter boxes were positioned on top of each lysimeter's monitoring well following lysimeter construction. As well, each lysimeter's storage zone was filled with water to test for leaks. When no leaks were detected, the water was then pumped down to a pre-determined datum (See Figure 2.1).

The Guelph lysimeters were fully functional by December 1989, while the Barrie lysimeters were fully operational by January 1, 1990. The landfill covers themselves, however, were not fully completed. The final loam cover and seeding on the section of the landfill where the lysimeters were installed was completed at Guelph in April 1990. The 1.5 m deep sand cover over the area where the lysimeters were installed at Barrie was applied in November 1989 and supplemented with 15 cm of sand in June 1990. No seeding has been completed to date at Barrie. This conforms to the normal maintenance routine at the Barrie site. Some vegetation is expected to establish naturally with time.

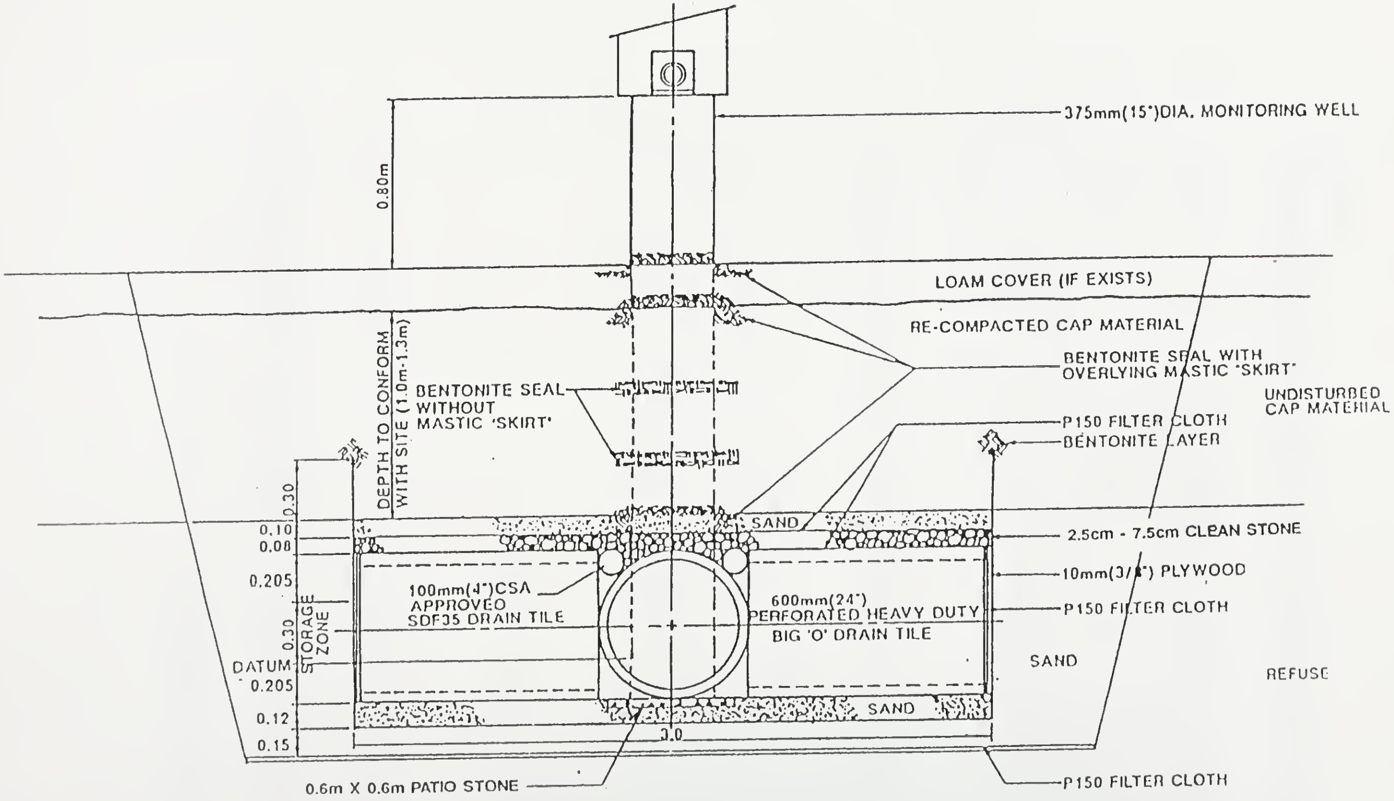
Detailed Description of the Lysimeter Installation

Material Preparation

1. Obtain the primary materials required to construct the lysimeter (see list of materials) and have delivered to the construction site.

2. Cut the 600 mm dia. Big "O" tile into 1.2 m and 1.5 m lengths in the most efficient way possible from the standard lengths. When complete, one has four times as many 1.2 m long tiles as 1.5 m long tiles. Thus, for one lysimeter, have eight short tiles and two long tiles.

3. At one end of each 1.5 m long tile cut out a semi-circular section to enable the pipe to fit around the lysimeter's monitoring well.


375mm(15")DIA. MONITORING WELL
0.80m
LOAM COVER (IF EXISTS)
RE-COMPACTED CAP MATERIAL
BENTONITE SEAL WITH OVERLYING MASTIC 'SKIRT'
UNDISTURBED CAP MATERIAL
DEPTH TO CONFORM WITH SITE (1.0m-1.3m)
BENTONITE SEAL WITHOUT MASTIC 'SKIRT'
P150 FILTER CLOTH
BENTONITE LAYER
0.30
0.10
0.08
0.205
0.30
DATUM
0.205
0.12
0.15
STORAGE ZONE
SAND
2.5cm - 7.5cm CLEAN STONE
10mm(3/8") PLYWOOD
100mm(4")CSA APPROVED SDF35 DRAIN TILE
600mm(24") PERFORATED HEAVY DUTY BIG 'O' DRAIN TILE
P150 FILTER CLOTH
SAND
REFUSE
SAND
3.0
0.6m X 0.6m PATIO STONE
P150 FILTER CLOTH

Source: Ecologists Limited, August 1991. page 5.

Figure 2.1 A cross section of the lysimeters used at Guelph and Barrie Landfills.

4. Wrap one end of each 600 mm dia. Big "O" tile with a 1.0 m x 1.0 m piece of filter cloth. Secure the filter cloth to the tile with plastic cord. For the longer 1.5 m tiles, wrap the end that was not cut to fit around the monitoring well.

5. Construct the wooden frame used to support the liner during lysimeter construction. The frame is to be 3.0 m x 3.0 m x 1.30 m high. Braces are to be placed on the outside of the frame.

6. Cut 1 cm wide by 15 cm long slots at 10 cm spacings around the perimeter of the bottom 60 cm of the monitoring well.

7. Cut from the plywood sheets, two smaller sheets with dimensions 0.6 m x 1.4 m and a third smaller sheet that is 0.7 m x 0.7 m. Smooth and round all edges with a belt sander.

8. Measure off a 132 cm length of Mel-rol membrane material and cut from the supply roll. Cut this piece lengthwise into four equally-sized (i.e. 20 cm wide) strips. With the paper side up, mark the midpoint of the width of this strip and draw a centre-line along the length of each strip. Mark off 10 cm intervals along its length. With a utility knife, cut a slit at each 10 cm interval and extend the slit to the midpoint line marked previously. Do the same for all Mel-rol membrane strips. This is then ready to be applied as a component of the mastic Mel-rol/bentonite "skirt".

On-Site Construction

9. Set-up a surveying level and tie to a permanent benchmark.

10. Measure and stake the area where the lysimeter is to be installed. For this study, three lysimeters were placed at a 30 m spacing, measured from the centreline of adjacent lysimeter monitoring wells.

11. With a backhoe dig a hole in the landfill cover at the proposed lysimeter location. Take cap moisture and density readings at 15 cm intervals in this hole using a CPN Moisture/Density probe and record for reference when replacing the cover over the lysimeter following its construction. If no cap exists at the time of lysimeter construction, this step can be skipped.

12. Excavate a minimum 4.5 m x 4.5 m hole in the landfill cover in the area where the lysimeter is to be installed. Stop when the top garbage layer is reached. Square off and smooth out.

13. Record the depth of the cover material.

14. Excavate the garbage material to a depth of 1.2 m below the cover material. Keep the pile of excavated garbage separate from the pile of cover material. Square off and smooth out the hole as best as possible once the required depth is reached.

15. Lay a 3.3 m x 3.3. m section of filter cloth in the bottom of the hole.

16. Place 20 cm of screened sand on top of the filter cloth and pack to firm the base. Record the

finished grade of this base layer using the surveying equipment.

17. Position the previously constructed wooden frame in the excavated hole.

18. Attach the pre-fabricated liner to the wooden frame by folding over the top 5 cm of liner material on the wooden frame and stapling it to the frame. Care should be taken to ensure the liner fits squarely on the frame.

19. Place 12 cm of screen sand inside the lysimeter. Fill around the outside of the lysimeter at the same time to maintain vertical liner walls. Pack the sand. Use the surveyor's level to measure sand layer depth and assist in levelling the layer. Record final layer elevation and relate it to a known benchmark.

20. Locate the centre of the lysimeter. Excavate just enough sand to allow the patio stone to be set in place. The patio stone is to be set flush with the sand layer. Use the surveying equipment to ensure the patio stone is level and at the proper elevation. Record the patio stone's elevation and relate it to a known benchmark.

21. Cut a 6 m long piece of filter cloth from 3.3 m wide roll and lay it over the patio stone and sand layer in the lysimeter. Temporarily staple it to the frame to hold it in place.

22. Cut two 1.5 m long pieces of filter cloth and drape them over the two remaining sides whose lysimeter walls are exposed. Temporarily staple the filter cloth to the frame.

23. Place four of the 1.2 m long 600 mm dia. Big "o" tiles inside the lysimeter. Position side-by-side in such a manner that the space between adjacent tile is minimized. the filter cloth wrapped end of the pipe is to face the outside wall of the lysimeter.

24. Position two 0.6 m x 1.4 m pre-cut sheets of plywood along the outside ends of the 1.2 m long Big "O" tile.

25. Place one of the 1.5 m long Big "O" tiles in the storage zone adjacent, to and perpendicular to, the 1.2 m long Big "o" tile already in place. The filter cloth wrapped end of the pipe is to be against the lysimeter liner wall.

26. Cut the monitoring well to the desired final height allowing about 4 ft. to extend above the finished landfill cover grade. Set the monitoring well in place, positioning it in the centre of the previously installed patio stone.

27. Position the remaining Big "O" tile around the monitoring well in a similar manner described for the tile already in position.

28. Place two 0.6 m x 1.4 m pre-cut sheets of plywood along the ends of the 1.2 m long Big "O" tile just installed.

29. Place the two 0.7 m x 0.7 m pre-cut sheets of plywood along the ends of the 1.5 m long Big "O" tile.

30. Place enough 2.5 cm to 7.5 cm stone along the end of the outside 1.2 m long Big "O" tiles (i.e. where no plywood has been placed) in order to securely hold the Big "O" tile in place.

31. Backfill the outside of the lysimeter hole with sand at the same time the rock is being added to maintain vertical sidewalls.

32. With the storage zone Big "O" tile firmly in position, continue to backfill and pack the outside of the lysimeter with sand maintaining a vertical liner wall at all times until the sand around the outside of the lysimeter reaches the same elevation as the top of the Big "O" tile inside the lysimeter.

33. Place the SDF 35 tile in the recesses between the in-place Big "O" tile; cutting as necessary to enable a proper fit.

34. Cut a 3.3 m long section from the 3.3 m wide roll of filter cloth. Cut a series of slits in the centre of the filter cloth. Slide the filter cloth over the monitoring well and spread it out over the storage zone tile. Securely tie the filter cloth around the monitoring well.

35. Place an 8 cm layer of 2.5 cm to 7.5 cm stone over the filter cloth and level off. Record the final elevation of this stone layer, relating it to the permanent benchmark using the survey equipment.

36. Continue to fill and pack the outside of the lysimeter with sand to the same depth as the layers on the inside of the lysimeter.

37. Cut a section of filter cloth as before to allow it to slide over the monitoring well and spread it over the stone. Securely tie the filter cloth around the monitoring well. Wrap a 10 cm wide strip of Mel-rol membrane around the well to further seal the area.

38. Place and pack a 10 cm layer of sand over the filter cloth. Relate the sand layer to a permanent benchmark using the surveying equipment. Continue to bring the outside of the lysimeter up at the same time.

39. Install a Mel-rol/bentonite "skirt" around the monitoring well by completing the following steps:

    - dig a 4 cm wide x 4 cm deep trench around the perimeter of the monitoring well,
    - fill the trench with bentonite, compacting as much as possible,
    - take a pre-cut Mel-rol membrane strip and with the slitted side toward the bottom, peal off the paper backing on the non-slitted half and wrap tightly and securely around the monitoring well,
    - take a second pre-cut Mel-rol membrane strip and wrap as with the first strip, only off-set so that the flaps of the "skirt" of the second strip cover the slits of the first strip,

- Liberally apply the Mel-role mastic material to the top edge of the Mel-rol membrane to seal the "skirt", and
- spread bentonite over the "skirt" to complete the seal.

40. Remove the filter cloth previously attached to the lysimeter frame from the frame, turning it into the centre of the lysimeter.

41. Apply the previously excavated cover material in 15 cm lifts.

42. The density of each lift is checked using the CPN moisture/density probe. The lift is compacted until the original cover density (measured when the cover was excavated) is achieved.

43. A bentonite seal is placed along the perimeter of the lysimeter to avoid preferential flow along the liner.

44. A Mel-rol/bentonite "skirt" is installed around the monitoring well at each point where there is a change in cover material (e.g. at the sand/cover material interface and at the cap material/loam topsoil interface). Follow the installation procedure outlined in step 39.

45. Place bentonite around the well following every second lift (or every 0.3 m).

46. The cover is replaced in 15 cm lifts until the excavated area is again flush with the surrounding cover. Heavy equipment (backhoe) traffic directly over the lysimeter is possible once 90 cm of cover material has been applied.

47. The lysimeters are filled with water to test for leaks.

48. The lysimeters are pumped down to a pre-set datum.

49. A cover is placed over the monitoring well and the float-and-pulley water-level recorder is installed.

LIST OF MATERIALS REQUIRED FOR CONSTRUCTING A LYSIMETER

NO.	ITEM	UNIT	QUANTITY
1	3.0 m x 3.0 m x 1.35 m x 1 mm thick (40 mil). High Density PVC Prefabricated Liner	Each	1
2	600 mm inside dia. Class 210 Perforated Heavy Duty Corrugated Polyethylene Pipe (Big "O" tile)	m	12
3	100 mm inside dia. SDF 35 3-Hole Drain Tile (SDF 35 tile)	m	16
4	380 mm Inside Dia. Bell & Spigot Sewer Pipe (for Monitoring Well)	Each	1
5	Mirafi PI50 (or equivalent) Filter Cloth	m^2	100
6	0.6 m x 0.6 m x 5 cm thick Patio Stone	Each	1
7	5 cm x 5 cm x 3.3 m long Spruce Lumber	Each	11
8	1.2 m x 2.4 m x 10 mm thick Spruce Plywood	Each	2
9	Standard Bentonite Sealant	45 kg bag	2
10	Mel-rol (or equivalent) Membrane and Mel-rol (or equivalent) Mastic	m^2 litres	1.5 2
11	Screened Sand	Tonnes	40
12	2.5 cm to 7.5 cm Clean Stone	Tonnes	7.0
13	Monitoring Well Cover	Each	1

APPENDIX C

LYSIMETER COVER MATERIAL

LYSIMETER COVER MATERIAL

SITE	COVER THICKNESS	COVER MATERIAL	VEGETATIVE COVER
Britannia	0.20 m 0.91 m	loam top soil clay	-prior to November 1991 the vegetation on the lysimeters was patchy to bare -in November 1991 sod was placed on all 4 lysimeters -by the summer of 1993, some bare patches on all 4 lysimeters became prevalent
Guelph	0.20 m 1.00 m	loam top soil gravelly clay	-prior to October 1991 the vegetation on the lysimeter was very patchy to bare -in October 1991 the completed cells at the landfill were re-seeded, this included the 3 lysimeters -the vegetation has taken but it is very patchy over the 3 lysimeters(mixture of grass and weed) -in June 1993 lysimeter 1 & 3 were stripped and reseeded
Barrie	0.15 m 1.50 m	sand sand	-prior to June 1992 the vegetation on the lysimeters was very patchy to bare -in June 1992 the completed cells at the landfill were hydro seeded again, this included the 3 lysimeters -the vegetation has taken but it is very patchy over the 3 lysimeter (mostly weed like)

APPENDIX D

MONTHLY VOLUMETRIC MEASUREMENTS

MONTHLY VOLUMETRIC MEASUREMENTS

In October 1991 three consultants were contracted by MOE to collect and submit monthly infiltration data from the ten lysimeters. The consultants were required to measure and record the stored volume of infiltration from each of the lysimeters at their sites once a month. The water levels in the monitoring wells were to be recorded with the date and time before and after pumping. To collect data that were representative of the total amount of water which infiltrated in a given month, it was important that the lysimeters were pumped down to the same datum established for each lysimeter.

In assessing the data, the final depth to water (datum level) taken after each monthly pumping session was examined to insure that a consistent datum level was obtained in each of the lysimeters (see Tables D.1 to D.3). Although some problems were encountered, a fairly consistent final depth to water was achieved at the Guelph and Barrie sites. Inconsistent levels were observed at the Britannia Road Landfill site mainly due to intrusion of gravel into the base of the monitoring well. This is discussed later in this Appendix.

A brief description of the pumping methods used and some of the problems encountered at each of the landfill sites is provided below.

A similar procedure was used at the Guelph and Barrie Landfill sites to determine how much to pump out. At both sites an electric submersible pump equipped with a metal cage footing was lowered into the monitoring well and set on the lysimeter's patio-stone base. The metal cage footing was fastened to the bottom of the submersible pump to raise the pump above the protective sand layer. This would allow water to only drain from the lysimeter storage area. The monthly volume of water was determined by pumping the water into a graduated container.

In early April 1993, the MOEE was informed that the datum depths at each lysimeter at the Guelph Landfill site had changed. As shown in Table D.2, the datum depths for lysimeters 1, 2 and 3 for the March pump-out period had increased about 5-15mm from the original. To determine whether the distance from the patio stone to the top of the monitoring well was changing, three different measurement points along the top of the monitoring well were selected for each monitoring well (refer to Table D.4). From April 1993 to April 1994, measurements from the top of the monitoring well to the patio stone were taken. It was confirmed in April 1994 that the changes in datum level were either due to the movement of the patio stone settling downward or the monitoring well heaving upward. As indicated in Table D.2, the pump-out session on April 4th, 1994 exhibited another downward movement of the datum level for lysimeter 2 and 3. The distance from the top of the monitoring well to the patio stone was taken on April 11th, 1994 and differed from measurements taken before April 1994 (refer to Table D.4). These changes in the datum depth appear to be a temporary problem, and usually by the next pumping session the lysimeters stabilized, and a new datum level could be established. Without a rigorous monitoring protocol in place, it is not certain how much these changes in datum depth affect the overall results. It appears that the data collected were only be temporarily affected during these incidents and therefore may not significantly affect the overall amount of infiltration measured. Otherwise, the lysimeters at the Guelph Landfill site were pumped within 5mm of the final depth datum each month.

Measurements to the patio stone for each lysimeter at the Barrie site were also taken. As shown in

Table D.5, there were no obvious signs of the patio stone settling/moving at the Barrie Landfill; however, the difference between the final water level measurement and the established final depth datum level during some months was between 1.0-35.0mm (refer to Table D.3). The differences are mostly attributed to inadequacies in the pumping practices used where the lysimeters were not pumped down to the same final depth datum every month. These errors will affect some of the monthly infiltration totals but should have little/no effect on the outcome of the seasonal and annual infiltration totals.

There were several pumping techniques used with the lysimeters at the Britannia Road Landfill. Before June 1991, the procedure for pumping the Britannia Road lysimeters was different from the method used at Guelph and Barrie. The electric submersible pump rested directly on the patio stone and pumped until such time that no more water could be recovered from the lysimeter. This method of pumping caused the level of water to fall below the storage zone. Therefore, in June 1991, a metal case footing, similar to the one used for Guelph and Barrie was attached to the bottom of the pump. This raised the pump considerably above the water level and consequently lysimeters 1, 2, 3, and 4 could not be pumped until June 1992, January 1992, April 1992 and June 1992, respectively.

In May 1992, MOEE was informed that the bottom elevations at all the lysimeters at Britannia were changing. Intrusion of gravel into the well bottoms was making it difficult to rest the pump at a consistent point in the well. As a result, the lysimeters could not be pumped down to the same datum level. On June 3 1992, a new pumping procedure was established which suspended the pump on a chain attached to a hook on the outside of each monitoring well casing. The pumping procedure modification temporarily interfered with the data collection and consequently, data collected from October 1991 to May 1992 have been omitted from this report.

The final water level measurements taken after each pumping session for all the lysimeters at the Britannia Road Landfill site from June 1992 to February 1993 varied significantly from month to month. On several occasions the lysimeters were not pumped even though water infiltrated since the last pumping session. The difference between the final water level and the established datum during some months was 1.0-90.0mm (refer to Table D.1). As of March 1993, these differences decreased substantially. However, other obstacles such as barometric pressure and the intrusion of gravel into the bottom of the monitoring wells continued to impede the collection of data. The problems that barometric pressure changes had on the collection of data are discussed in Appendix E. Because the bottom of the monitoring wells were not screened, gravel intruded into the monitoring wells. On several occasions the pump was resting on top of the gravel rather then suspending freely into the well. To alleviate the problems associated with the gravel intrusion, some of the lysimeters monitoring wells were dredged, however the measurements to the patio stone, as taken at the Guelph and Barrie site, could not be taken at the Britannia Road site because of the gravel intrusion. Without having at least one lysimeter with good quality data from which to compare results, it was not possible to fully assess whether the problems encountered at the Britannia site had a significant impact on the quality of data collected.

TABLE D.1 BRITANNIA ROAD LANDFILL

MONTHLY FINAL DEPTH TO WATER MEASUREMENTS

Pump Out Date	Lysimeter Final Depth Measurement (metres) #1	#2	#3	#4	Notes: the final depth to water was taken from the top of the monitoring well down
Oct 29/91	* 2.387	* 2.350	* 2.382	* 2.364	
Nov 26/91	* 2.393	* 2.350	* 2.379	* 2.362	
Dec 30/91	* 2.360	* 2.331	* 2.369	* 2.350	
Jan 27/92	* 2.335	2.356	* 2.344	* 2.321	
Feb 24/92	* 2.323	* 2.338	* 2.344	* 2.321	
On Feb 27/92 A New Datum Was Established by MOE for #2 & #3, water level housing were installed					
Marc 24/92	* 2.330	* 2.329	* 2.373	* 2.325	
Aprl 27/92	* 2.308	2.333	2.371	* 2.298	
May 4/92	* 2.306	* 2.314	* 2.185	* 2.301	
May 11/92	* 2.304	* 2.312	2.358	* 2.306	Returned to site to pump #3
May 26/92	* 2.294	2.316	2.352	* 2.308	
On June 03/92 MOEE installed the hook and chain system. New datum to be established by the next pumping session					
June 23/92	2.410	2.325	2.381	2.321	MOEE on site to demonstrate new pumping method
July 27/92	2.413	2.345	2.381	* 2.310	
Aug 6/92	2.420	2.365	2.390	2.322	MOEE pump out
Aug 24/92	* 2.370	* 2.360	* 2.383	* 2.325	
Sept 24/92	* 2.339	* 2.331	* 2.369	* 2.314	
Oct 23/92	2.402	2.362	2.300	2.407	Pump was placed between well and housing at lys. #4.
Nov 25/92	2.424	2.364	2.387	2.314	
Dec 23/92	2.405	2.341	2.373	2.310	
Jan 7/93	* 2.339	* 2.311	* 2.330	2.307	MOEE requested that #4 be pumped
Jan 26/93	2.415	2.351	2.378	2.264	
Feb 22/93	2.426	2.363	2.396	2.278	
March 10/93					
MOEE relocated hook on #4					
Mar 29/93	* 2.420	* 2.365	* 2.382	2.430	
Aprl 26/93	* 2.418	2.362	2.376	* 2.394	
May 25/93	2.420	2.359	2.379	2.472	
June 17/93 MOEE dredged and pumped lysimeter four. MOEE dredged, pumped, and lowered pump on lysimeter three.					
June 24/93	2.419	2.364	2.491	2.475	
July 23/93	2.419	2.364	2.491	2.478	

*lysimeter was not pumped

TABLE D.1 BRITANNIA ROAD LANDFILL

MONTHLY FINAL DEPTH TO WATER MEASUREMENTS

Pump Out Date	Lysimeter Final Depth Measurment (metres) #1	#2	#3	#4	Notes: the final depth to water was taken from the top of the monitoring well down
Aug 25/93	2.423	2.361	2.495	2.470	
Sep 28/93	2.414	2.354	2.495	2.475	MOEE dredged 28th – Pumped 30th
Sep 29/93	2.414	2.354	2.495	2.495	Golder returned to mainly check #4 lys.
Oct 29/93	* 2.424	* 2.368	* 2.491	2.489	Lys. #4 datum may have to be re–established
Nov 29/93	2.424	2.371	2.494	#	returned Nov. 30 to reach datum mark
Nov 30/93	n/a	n/a	n/a	2.491	
Dec 29/93	2.422	2.367	2.490	2.492	
Jan 26/94	* n/a	2.366	* n/a	2.489	
Feb 28/94	* n/a	* n/a	* n/a	2.494	
Mar 25/94	2.423	* 2.360	* 2.495	2.496	
Apr 26/94	2.420	2.363	2.489	2.494	
May 27/94	2.418	2.363	2.490	2.492	
Jun 28/94	2.417	2.365	2.490	2.494	
July 26/94	2.419	2.363	2.490	2.494	
Aug 26/94	2.420	2.370	2.490	2.495	
Sep 26/94	2.420	2.365	2.490	2.495	
Oct 28/94	* 2.430	* 2.410	* 2.520	2.495	Water level in #1,2+3 was below datum, possible leak

* lysimeter was not pumped

TABLE D.2 GUELPH LANDFILL
MONTHLY FINAL DEPTH TO WATER MEASUREMENTS

Pump Out Date	Lysimeter Final Depth Measurements (metres) #1	#2	#3	Notes: the final depth to water was taken from the top of the monitoring well down
Oct 31/91	* 2.708	* 2.710	* 2.707	
Nov 26/91	* 2.710	* 2.710	* 2.703	
Dec 31/91	2.706	2.706	2.705	
Jan 30/92	2.708	2.715	2.707	Lysimeter #2 final depth increased.
On Feb 24/92 MOEE removed housing from #1 and replaced housing on #3. New datum is established.				
Mar 2/92	2.684	2.719	2.709	
Apr 1/92	* 2.686	* 2.718	2.709	
May 1/92	2.681	2.721	2.710	
May 29/92	2.681	2.721	2.710	
Jun 30/92	2.682	2.722	2.711	
Jul 31/92	2.682	2.722	2.711	
Aug 31/92	2.682	2.719	2.711	
Oct 1/92	2.682	2.721	2.710	
Nov 2/92	2.682	2.721	2.710	
Nov 30/92	2.679	2.718	2.706	
Dec 30/92	2.679	2.718	2.706	
Feb 1/93	2.683	2.723	2.710	
Mar 1/93	* 2.683	* 2.723	* 2.712	
Mar 31/93	2.687	2.734	2.727	All final depths appear to have moved down.
Apr 30/93	2.679	2.726	2.726	Lysimeters 1 and 2 returned to the final depths recorded before Mar 31/93.
May 31/93	2.679	2.726	2.730	
Jun 30/93	2.679	2.726	2.729	
Jul 29/93	2.679	2.726	2.729	
Aug 31/93	2.679	2.724	2.729	
Oct 01/93	2.679	2.723	2.729	
Nov 01/93	* 2.679	2.722	2.726	
Dec 01/93	* 2.681	2.722	2.722	
Dec 30/93	2.681	2.722	2.735	
Feb 03/94	2.679	* 2.720	* 2.730	
Feb 28/94	* 2.680	* 2.720	2.730	
Apr 04/94	2.680	2.736	2.754	Final depths for Lysimeters 2 and 3 have move down.
Apr 29/94	2.680	2.723	2.736	Lysimeter 2 recovered to original final depth datum, final depth datum has changed for lysimeter 3.

*lysimeter was not pumped

TABLE D.2 GUELPH LANDFILL

MONTHLY FINAL DEPTH TO WATER MEASUREMENTS

Pump Out Date	Lysimeter Final Depth Measurements (metres) #1	#2	#3	Notes: the final depth to water was taken from the top of the monitoring well down
May 31/94	2.680	2.722	2.737	
Jun 30/94	2.682	2.723	2.736	
Aug 03/94	2.684	2.723	2.736	
Aug 30/94	2.683	2.722	2.738	
Sep 30/94	* 2.683	2.722	2.737	
Oct 31/94	* 2.684	* 2.723	* 2.738	

*lysimeter was not pumped

TABLE D.3 BARRIE LANDFILL
MONTHLY FINAL DEPTH TO WATER MEASUREMENTS

Pump Out Date	Lysimeter Final Depth Measurements #1	#2	#3	Notes: the final depth to water was taken from the top of the monitoring well down
Nov 01/91	* 3.397	* 3.390	* 3.385	
Dec 02/91	3.405	* 3.380	3.410	
Dec 31/91	3.415	3.415	3.418	
Feb 03/92	* 3.395	* 3.395	* 3.395	
On Feb 26/92 MOEE removed housing from #3. A new datum is established for #3.				
Feb 28/92	3.415	3.415	3.388	
Mar 20/92	* 3.405	* 3.390	* 3.383	
Apr 01/92	3.420	3.405	* 3.381	
May 01/92	3.420	3.411	3.385	
May 29/92	3.415	3.411	3.390	
Jul 02/92	3.418	3.397	* 3.374	
Aug 05/92	* 3.407	3.411	3.393	
Sep 01/92	3.418	* 3.405	* 3.384	
Oct 02/92	3.418	* 3.395	3.395	
Oct 30/92	3.418	3.413	* 3.384	
Dec 01/92	3.416	3.403	3.388	
Jan 04/93	3.416	3.410	3.390	
Feb 02/93	3.416	3.410	3.387	
Mar 02/93	* 3.400	* 3.405	* 3.372	
Mar 29/93	3.416	* 3.394	3.389	
May 03/93	3.416	3.410	3.390	
Jun 01/93	3.420	3.410	3.388	
Jun 30/93	3.415	3.415	3.390	
Jul 30/93	3.415	3.415	3.390	
Sep 02/93	3.415	3.415	3.390	
Oct 01/93	3.415	3.415	3.390	
Nov 01/93	3.415	3.415	3.390	
Dec 01/93	3.415	3.415	3.390	
Jan 04/94	3.415	3.415	3.390	
Feb 02/94	3.415	3.415	3.390	
Feb 28/94	3.415	3.415	3.390	
Mar 31/94	3.415	3.415	3.390	
May 02/94	3.415	3.415	3.390	

* lysimeter was not pumped

TABLE D.3 BARRIE LANDFILL

MONTHLY FINAL DEPTH TO WATER MEASUREMENTS

Pump Out Date	Lysimeter Final Depth Measurements #1	#2	#3	Notes: the final depth to water was taken from the top of the monitoring well down
Jun 01/94	3.415	3.415	3.390	
Jun 30/94	3.415	3.415	3.390	
Aug 03/94	3.415	3.415	3.390	
Sep 01/94	3.415	3.415	3.390	
Oct 03/94	3.415	3.415	3.390	
Oct 28/94	3.415	3.415	3.390	

* lysimeter was not pumped

TABLE D.4 GUELPH LANDFILL

MEASUREMENTS TO PATIO STONE

DATE	LYSIMETER #1 (metres)			LYSIMETER #2 (metres)			LYSIMETER #3 (metres)		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
Apr 13/93	2.893	2.888	2.893	2.931	2.929	2.931	2.935	2.941	2.934
May 31/93	2.887	2.884	2.887	2.927	2.926	2.932	2.934	2.942	2.936
Jun 14/93	2.888	2.888	2.889	2.930	2.930	2.929	2.946	2.937	2.936
Jun 28/93	2.885	2.888	2.890	2.925	2.930	2.929	2.940	2.940	2.935
Jul 12/93	2.885	2.889	2.889	2.927	2.925	2.930	2.943	2.936	2.936
Jul 27/93	2.885	2.889	2.889	2.921	2.925	2.926	2.946	2.941	2.935
Aug 09/93	2.885	2.889	2.888	2.929	2.927	2.927	2.945	2.939	2.935
Aug 23/93	2.885	2.889	2.890	2.923	2.920	2.920	2.944	2.939	2.935
Sep 07/93	2.885	2.889	2.886	2.920	2.921	2.920	2.940	2.935	2.935
Sep 20/93	2.885	2.887	2.887	2.910	2.919	2.911	2.940	2.939	2.937
Oct 04/93	2.885	2.888	2.888	2.919	2.920	2.911	2.940	2.942	2.934
Oct 25/93	2.883	2.887	2.888	2.912	2.918	2.918	2.940	2.938	2.933
Nov 08/93	2.881	2.886	2.887	2.913	2.920	2.917	2.932	2.935	2.932
Nov 22/93	2.881	2.887	2.887	2.913	2.925	2.918	2.936	2.935	2.936
Apr 11/94	2.888	2.892	2.890	2.936	2.937	2.935	2.957	2.961	2.953

Note: Three measurement points (F1, F2, F3) equally spaced around the top of the monitoring well were selected and marked at the top of each lysimeter monitoring well. Measurements are taken from these points down the side of well casing to the patio stone.

TABLE D.5 BARRIE LANDFILL

MEASUREMENTS TO PATIO STONE

DATE	LYSIMETER #1 (metres)			LYSIMETER #2 (metres)			LYSIMETER #3 (metres)		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
Apr 27/93	3.614	3.614	3.610	3.609	3.610	3.606	3.582	3.582	3.588
May 26/93	3.615	3.613	3.610	3.609	3.609	3.609	3.582	3.582	3.584
Jun 29/93	3.611	3.612	3.611	3.610	3.609	3.609	3.583	3.583	3.584
Jul 29/93	3.616	3.614	3.612	3.611	3.611	3.610	3.585	3.585	3.587
Aug 26/93	3.615	3.616	3.612	3.612	3.612	3.611	3.584	3.585	3.587
Sep 29/93	3.605	3.610	3.610	3.608	3.608	3.605	Field measurement error		
Oct 28/93	3.610	3.614	3.611	3.610	3.610	3.610	3.580	3.582	3.585
Nov 25/93	3.610	3.613	3.610	3.608	3.610	3.608	3.580	3.580	3.583
Apr 11/94	3.617	3.615	3.608	3.609	3.610	3.610	3.585	3.579	3.585
Jun 29/94	3.615	3.615	3.612	3.610	3.610	3.607	3.584	3.580	3.587

Note: Three measurement points (F1, F2, F3) equally spaced around the top of the monitoring well were selected and marked at the top of each lysimeter monitoring well. Measurements are taken from these points down the side of well casing to the patio stone.

TABLE D.6 BRITANNIA LANDFILL SITE MONTHLY TOTAL INFILTRATION
JUNE 1992 TO OCTOBER 1994

Britannia	Total Precipitation		Lysimeter 1		Lysimeter 2		Lysimeter 3		Lysimeter 4	
	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)
Jun 92	30.5	1.2	35.6	1.4	7.1	0.3	21.9	0.9	14.1	0.6
Jul 92	126.9	5.0	10.8	0.4	12.0	0.5	15.6	0.6	0.0	0.0
Aug 92	101.6	4.0	2.9	0.1	7.1	0.3	9.7	0.4	3.2	0.1
Sep 92	168.0	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct 92	67.2	2.6	8.6	0.3	13.7	0.5	10.8	0.4	76.9	3.0
Nov 92	108.4	4.3	37.1	1.5	36.9	1.5	45.3	1.8	9.4	0.4
Dec 92	36.1	1.4	35.2	1.4	32.3	1.3	25.8	1.0	15.3	0.6
Jan 93	79.9	3.1	38.7	1.5	35.5	1.4	34.4	1.4	44.9	1.8
Feb 93	36.9	1.5	15.1	0.6	12.9	0.5	22.8	0.9	9.2	0.4
Mar 93	31.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	32.2	1.3
Apr 93	81.8	3.2	0.0	0.0	24.7	1.0	26.9	1.1	0.0	0.0
May 93	36.1	1.4	10.6	0.4	17.4	0.7	23.7	0.9	50.4	2.0
Jun 93	138.5	5.5	4.8	0.2	14.0	0.6	17.7	0.7	4.3	0.2
Jul 93	63.5	2.5	5.4	0.2	7.7	0.3	11.8	0.5	5.6	0.2
Aug 93	72.1	2.8	6.5	0.3	4.2	0.2	11.3	0.4	5.4	0.2
Sep 93	65.8	2.6	1.5	0.1	0.0	0.0	10.3	0.4	10.7	0.4
Oct 93	68.2	2.7	3.2	0.1	6.2	0.2	1.3	0.1	7.3	0.3
Nov 93	65.2	2.6	1.6	0.1	3.1	0.1	3.2	0.1	17.8	0.7
Dec 93	28.8	1.1	6.5	0.3	5.6	0.2	6.6	0.3	44.6	1.8
Jan 94	29.2	1.1	0.0	0.0	7.5	0.3	0.0	0.0	10.8	0.4
Feb 94	52.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.3
Mar 94	31.2	1.2	5.2	0.2	0.0	0.0	0.0	0.0	6.7	0.3
Apr 94	96.2	3.8	14.6	0.6	23.1	0.9	14.0	0.6	9.7	0.4
May 94	86.2	3.4	12.3	0.5	39.4	1.6	30.3	1.2	13.2	0.5
Jun 94	47.4	1.9	7.8	0.3	20.4	0.8	18.3	0.7	11.3	0.4
Jul 94	87.0	3.4	8.1	0.3	3.7	0.1	14.0	0.6	10.2	0.4
Aug 94	68.6	2.7	2.9	0.1	5.1	0.2	16.1	0.6	9.1	0.4
Sep 94	50.8	2.0	1.8	0.1	2.6	0.1	12.9	0.5	6.5	0.3
Oct 94	33.4	1.3	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.3

NOTE: Volumes of infiltration measured were converted to a depth of water over the lysimeter's 9.3 m ^ 2 surface area

TABLE D.7 GUELPH LANDFILL SITE MONTHLY TOTAL INFILTRATION OCTOBER 1991 TO OCTOBER 1994

Guelph	Total Precipitation		Lysimeter 1		Lysimeter 2		Lysimeter 3	
	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)
Oct 91	74.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0
Nov 91	44.6	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Dec 91	91.3	3.6	75.6	3.0	59.4	2.3	104.2	4.1
Jan 92	28.2	1.1	69.0	2.7	71.2	2.8	84.7	3.3
Feb 92	29.6	1.2	5.1	0.2	9.6	0.4	19.3	0.8
Mar 92	29.2	1.1	0.0	0.0	0.0	0.0	11.4	0.4
Apr 92	138.2	5.4	91.9	3.6	92.1	3.6	39.4	1.6
May 92	55.3	2.2	63.9	2.5	46.7	1.8	37.7	1.5
Jun 92	67.8	2.7	15.6	0.6	13.8	0.5	13.7	0.5
Jul 92	162.7	6.4	48.9	1.9	14.4	0.6	14.2	0.6
Aug 92	140.9	5.5	55.0	2.2	22.8	0.9	29.7	1.2
Sep 92	127.0	5.0	35.1	1.4	35.6	1.4	32.3	1.3
Oct 92	85.0	3.3	46.9	1.8	46.9	1.8	42.4	1.7
Nov 92	121.7	4.8	101.7	4.0	106.7	4.2	70.0	2.8
Dec 92	63.8	2.5	47.8	1.9	75.1	3.0	70.2	2.8
Jan 93	107.5	4.2	41.0	1.6	48.7	1.9	37.8	1.5
Feb 93	30.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Mar 93	44.0	1.7	3.1	0.1	5.0	0.2	13.2	0.5
Apr 93	83.5	3.3	80.6	3.2	113.3	4.5	44.4	1.7
May 93	51.2	2.0	51.7	2.0	62.0	2.4	38.7	1.5
Jun 93	108.4	4.3	17.8	0.7	33.6	1.3	25.6	1.0
Jul 93	111.5	4.4	14.8	0.6	20.4	0.8	18.3	0.7
Aug 93	49.6	2.0	10.0	0.4	8.8	0.3	14.2	0.6
Sep 93	93.6	3.7	2.9	0.1	1.9	0.1	1.0	0.0
Oct 93	64.4	2.5	0.0	0.0	0.6	0.0	24.7	1.0
Nov 93	63.8	2.5	0.0	0.0	15.7	0.6	82.4	3.2
Dec 93	36.4	1.4	3.2	0.1	23.6	0.9	90.6	3.6
Jan 94	85.8	3.4	1.3	0.1	0.0	0.0	0.0	0.0
Feb 94	34.8	1.4	0.0	0.0	0.0	0.0	2.1	0.1
Mar 94	62.6	2.5	0.4	0.0	8.9	0.4	12.2	0.5
Apr 94	100.2	3.9	19.2	0.8	28.6	1.1	69.6	2.7
May 94	124.2	4.9	87.0	3.4	210.7	8.3	120.9	4.8
Jun 94	70.8	2.8	47.8	1.9	70.6	2.8	29.7	1.2
Jul 94	85.4	3.4	16.8	0.7	24.4	1.0	19.9	0.8
Aug 94	66.9	2.6	5.0	0.2	2.8	0.1	3.3	0.1
Sep 94	34.6	1.4	0.0	0.0	0.6	0.0	0.1	0.0
Oct 94	37.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0

NOTE: Volumes of infiltration measured were converted to a depth of water over the lysimeter's 9 m ^ 2 surface area

TABLE D.8 BARRIE LANDFILL SITE MONTHLY TOTAL INFILTRATION
OCTOBER 1991 TO OCTOBER 1994

Barrie	Total Precipitation		Lysimeter 1		Lysimeter 2		Lysimeter 3	
	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)
Oct 91	65.6	2.6	0.0	0.0	0.0	0.0	0.0	0.0
Nov 91	46.0	1.8	18.3	0.7	0.0	0.0	24.2	1.0
Dec 91	63.2	2.5	63.3	2.5	42.3	1.7	32.8	1.3
Jan 92	41.3	1.6	0.0	0.0	0.0	0.0	0.0	0.0
Feb 92	41.0	1.6	32.6	1.3	26.4	1.0	28.9	1.1
Mar 92	41.6	1.6	17.6	0.7	21.1	0.8	0.0	0.0
Apr 92	63.2	2.5	62.1	2.4	18.8	0.7	47.4	1.9
May 92	32.2	1.3	18.9	0.7	26.1	1.0	26.3	1.0
Jun 92	59.6	2.3	16.6	0.7	0.9	0.0	0.0	0.0
Jul 92	107.2	4.2	0.0	0.0	23.9	0.9	21.8	0.9
Aug 92	77.7	3.1	30.1	1.2	0.0	0.0	0.0	0.0
Sep 92	95.7	3.8	31.7	1.2	0.0	0.0	22.2	0.9
Oct 92	50.3	2.0	18.0	0.7	22.4	0.9	0.0	0.0
Nov 92	125.2	4.9	125.9	5.0	19.4	0.8	60.9	2.4
Dec 92	123.2	4.9	68.9	2.7	28.7	1.1	32.2	1.3
Jan 93	91.0	3.6	69.4	2.7	20.0	0.8	46.7	1.8
Feb 93	68.6	2.7	0.0	0.0	0.0	0.0	0.0	0.0
Mar 93	42.0	1.7	191.1	7.5	0.0	0.0	148.9	5.9
Apr 93	73.2	2.9	151.7	6.0	49.4	1.9	149.4	5.9
May 93	80.2	3.2	31.9	1.3	23.3	0.9	23.9	0.9
Jun 93	93.3	3.7	19.9	0.8	14.3	0.6	14.4	0.6
Jul 93	67.6	2.7	32.8	1.3	17.1	0.7	10.6	0.4
Aug 93	80.2	3.2	19.0	0.7	14.4	0.6	11.4	0.4
Sep 93	122.8	4.8	38.7	1.5	5.9	0.2	17.8	0.7
Oct 93	61.3	2.4	42.3	1.7	13.3	0.5	35.0	1.4
Nov 93	60.2	2.4	17.4	0.7	12.0	0.5	17.8	0.7
Dec 93	44.7	1.8	45.1	1.8	17.3	0.7	27.8	1.1
Jan 94	105.2	4.1	8.0	0.3	4.4	0.2	10.4	0.4
Feb 94	38.1	1.5	53.7	2.1	8.0	0.3	8.2	0.3
Mar 94	24.4	1.0	32.8	1.3	4.1	0.2	16.9	0.7
Apr 94	55.6	2.2	44.8	1.8	8.6	0.3	30.6	1.2
May 94	104.6	4.1	41.7	1.6	18.9	0.7	22.8	0.9
Jun 94	58.2	2.3	38.6	1.5	28.7	1.1	37.7	1.5
Jul 94	53.4	2.1	18.1	0.7	17.9	0.7	16.7	0.7
Aug 94	60.0	2.4	13.9	0.5	11.1	0.4	9.4	0.4
Sep 94	90.0	3.5	5.2	0.2	8.7	0.3	6.0	0.2
Oct 94	45.0	1.8	2.7	0.1	2.9	0.1	1.7	0.1

NOTE: Volumes of infiltration measured were converted to a depth of water over the lysimeter's 9 m ^ 2 surface area

APPENDIX E

WATER LEVEL DATA

WATER LEVEL RECORDER DATA

In addition to taking field water level measurements from the top of the monitoring well before and after each pump out session, Steven water level recorders (F-type) were installed in some of the lysimeter monitoring wells (see Table E.1) to provide a continuous record of water levels in these lysimeter storage zones. The purpose of obtaining continuous water level measurements from the lysimeters were to examine the mechanism of infiltration, to assist in verifying field water level measurements and to test if the lysimeters were leaking.

The hydrographs obtained from the Guelph and Barrie lysimeters did not exhibit any response to individual rainfall events but rather showed gradual water level increases in the storage zone. The water levels obtained from the hydrographs were within ±5mm of those taken by the tape method (see Tables E.2 to E.5). This provided verification of the field measurement data collected. The hydrographs did not show any water level decreases which would indicate that the lysimeters were leaking. The associated graphs on tables E6, E7 and E8 illustrate the linear relationship between the total volume pumped and the water level change measured for the three year monitoring period. There are several factors which could influence the relationship such as barometric effects, changes in lysimeter configuration and field measurement errors. As shown in the graphs appended to Table E6 and E7, there is very little scatter of the data which suggests that lysimeters 1, 2 and 3 at Guelph and lysimeters 1, 2 and 3 at Barrie have not been significantly affected by these three factors.

The hydrographs obtained at the Britannia Road Landfill lysimeters could not be fully interpreted due to interference from barometric effects. Irregular water level fluctuations are clearly shown on the water level charts. As discussed in Section 2, the problems encountered in early 1988 with barometric pressure effects at the Britannia Road Landfill site emerged again in the Spring of 1992. After the plugging of the vent holes in January 1991, the barometric pressure changes were not readily noticed because only one lysimeter was equipped with a water level recorder until March 1992 (see Table E.1). Also, the number of vent holes drilled and plugged varied from lysimeter to lysimeter which contributed to the extent that each lysimeter would respond to barometric pressure changes. It is not clear whether the barometric effects influenced the quantity of infiltration into the lysimeter but it is clear that erroneous field water level measurements would result from the effects of barometric pressure. Although it may not be exclusively due to the effects of barometric pressure, the scatter exhibited on the graphs appended to Table E8 for lysimeters 3 and 4 at Britannia is believed to be mostly a result of barometric effects.

Many attempts were made to alleviate these barometric effects. It was not until June 1993 that any of the hydrographs obtained from the lysimeters at the Britannia Road Landfill were free from barometric effects and could be interpreted. From the limited amount of data obtained, no further observations were formulated other than that already mentioned for Guelph or Barrie. After the disassembly of the water level recorders in December of 1993, it was more difficult to determine whether the barometric effect reappeared.

Although the water level recorders were beneficial as a quality control measure, they were all disassembled between November 1993 and December 1993 because of equipment breakdown and the lack of funds to replace or repair the equipment.

The response curves show a gradual steady increase in water level and therefore do not provide any more insight over that of Guelph or Barrie to the mechanism of infiltration. For this reason they have not be presented in this report but are available from the Science and Technology Branch.

TABLE E.1 WATER LEVEL RECORDER INSTALLATION

	LYSIMETER #1		*LYSIMETER #2*		*LYSIMETER #3*		*LYSIMETER #4*	
	Installed	Dissembled	Installed	Dissembled	Installed	Dissembled	Installed	Dissembled
Guelph			Sep 30, 1991 F–Type Stevens W.L. Recorder Time Scale – 1.2"/day(8 day clock) Gage Scale – 1:1	Nov 29, 1993	Sep 30, 1991 F–Type Stevens W.L. Recorder Time Scale – 1.2"/day(8 day clock) Gage Scale – 1:1	Nov 29, 1993		
Barrie	Feb 26, 1992 F–Type Stevens W.L. Recorder Time Scale – 0.3"/day(32 day clock) Gage Scale – 1:1	Nov 26, 1993	Feb 26, 1992 F–Type Stevens W.L. Recorder Time Scale – 0.3"/day(32 day clock) Gage Scale – 1:1	Nov 26, 1993				
Britannia			Mar 05, 1992 F–Type Stevens W.L. Recorder Time Scale – 0.3"/day(32 day clock) Gage Scale – 1:1	Dec 20, 1993	Mar 05, 1992 F–Type Stevens W.L. Recorder Time Scale – 0.3"/day(32 day clock) Gage Scale – 1:1	Dec 20, 1993	Oct 24, 1991 A71–Type Stevens W.L. Recorder Time Scale – 3cm/day(continuous strip chart) Gage Scale – 1:1	Dec 20, 1993

**WATER LEVEL HYDROGRAPHS ARE AVAILABLE
FROM SCIENCE AND TECHNOLOGY BRANCH**

TABLE E.2 WATER LEVEL RECORDER CHART ANALYSIS
GUELPH LANDFILL LYSIMETER 2

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	*Elapsed Time* (days)	*Chart Length* (inch)	*Chart Rate* (inch/day)	*Recorded Change* (metre)	*Field Measured Water Level* (metre)	*Water Level Change* (metre)	*Comments and Observations*
Sep 30,1991 to Oct 31	31.00	9.375	0.302	0.000	2.710	NA	
Oct 31 to Nov 26	26.18	7.750	0.296	0.000	2.710 2.710	0.000	
Nov 26 to Dec 06	9.77	1.500	0.154	0.009	2.710 2.701	0.009	
Dec 06 to Feb 24,1992	80.000	NA	NA	NA	NA	NA	Recorder removed on on dec 06 has been replaced
Feb 24 to Mar 02	6.92	8.063	1.166	0.002	2.709 2.707	0.002	and set to 8 days Pumpout Mar 02
Mar 02 to Mar 09	6.83	8.156	1.194	0.000	2.720 2.719	0.001	
Mar 09 to Mar 16	7.05	8.406	1.192	−0.002	2.719 2.721	−0.002	
Mar 16 to Mar 23	6.92	8.250	1.193	0.000	2.721 2.721	0.000	
Mar 23 to Mar 30	7.00	8.375	1.196	0.000	2.721 2.720	0.001	
Mar 30 to Apr 03	4.02	4.813	1.197	0.001	2.720 2.718	0.002	
Apr 03 to Apr 14	11.00	NA	NA	0.001	2.718 2.715	0.003	Recorder has been left for 11 days
Apr 14 to Apr 21	7.10	8.500	1.196	0.045	2.715 2.677	0.038	
Apr 21 to Apr 28	6.96	8.313	1.195	0.058	2.677 2.632	0.045	
Apr 28 to May 01	2.86	3.438	1.200	0.015	2.632 2.620	0.012	
May 01 to May 05	4.14	4.938	1.194	0.019	2.721 2.708	0.013	
May 05 to May 12	7.00	8.375	1.196	0.017	2.708 2.690	0.018	
May 12 to May 19	6.98	8.375	1.200	0.011	2.690 2.680	0.010	
May 19 to May 27	7.96	9.438	1.186	0.010	2.680 2.673	0.007	
May 27 to May 29	1.95	2.313	1.187	0.002	2.673 2.670	0.003	
May 29 to Jun 02	4.02	4.813	1.197	0.004	2.721 2.719	0.002	

TABLE E.2 WATER LEVEL RECORDER CHART ANALYSIS
GUELPH LANDFILL LYSIMETER 2

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	*Elapsed Time* (days)	*Chart Length* (inch)	*Chart Rate* (inch/day)	*Recorded Change* (metre)	*Field Measured Water Level* (metre)	*Water Level Change* (metre)	*Comments and Observations*
Jun 02 to Jun 10	7.98	9.469	1.187	0.005	2.719 2.716	0.003	
Jun 10 to Jun 18	7.98	9.469	1.187	0.003	2.716 2.714	0.002	
Jun 18 to Jun 24	6.00	7.156	1.193	0.004	2.714 2.711	0.003	
Jun 24 to Jun 30	5.95	7.125	1.197	0.002	2.711 2.707	0.004	
Jun 30 to Jul 07	6.99	8.375	1.198	0.001	2.724 2.723	0.001	
Jul 07 to Jul 15	8.00	9.469	1.184	0.003	2.723 2.721	0.002	
Jul 15 to Jul 21	6.04	7.219	1.195	0.005	2.721 2.718	0.003	
Jul 21 to Jul 29	7.95	9.469	1.191	0.009	2.718 2.710	0.008	
Jul 29 to Jul 31	2.08	2.469	1.187	0.002	2.710 2.708	0.002	
Jul 31 to Aug 05	4.93	2.781	0.564	0.004	2.722 2.724	−0.002	
Aug 05 to Aug 11	6.01	7.188	1.196	0.006	2.724 2.719	0.005	
Aug 11 to Aug 19	7.99	9.500	1.189	0.012	2.719 2.710	0.009	
Aug 19 to Aug 25	6.00	7.188	1.198	0.009	2.710 2.703	0.007	
Aug 25 to Aug 31	6.13	7.313	1.194	0.011	2.703 2.693	0.010	
Aug 31 to Sep 02	1.84	2.125	1.153	0.003	2.719 2.720	−0.001	
Sep 02 to Sep 08	6.04	7.188	1.190	0.008	2.720 2.713	0.007	
Sep 08 to Sep 15	6.88	8.063	1.173	0.012	2.713 2.705	0.008	
Sep 15 to Sep 24	9.16	9.313	1.017	0.015	2.705 2.692	0.013	
Sep 24 to Oct 01	6.92	8.250	1.193	0.010	2.692 2.685	0.007	
Oct 01 to Oct 08	6.80	8.094	1.190	0.007	2.721 2.719	0.002	

TABLE E.2 WATER LEVEL RECORDER CHART ANALYSIS

GUELPH LANDFILL LYSIMETER 2

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	*Elapsed Time* (days)	*Chart Length* (inch)	*Chart Rate* (inch/day)	*Recorded Change* (metre)	*Field Measured Water Level* (metre)	*Water Level Change* (metre)	*Comments and Observations*
Oct 08 to Oct 16	8.00	9.313	1.164	0.006	2.719 2.716	0.003	
Oct 16 to Oct 22	6.14	7.250	1.182	0.021	2.716 2.699	0.017	
Oct 22 to Oct 30	7.85	9.125	1.162	0.034	2.699 2.672	0.027	
Oct 30 to Nov 02	3.20	3.781	1.182	0.008	2.672 2.677	−0.005	
Nov 02 to Nov 04	1.79	1.688	0.942	0.005	2.721 2.717	0.004	
Nov 04 to Nov 10	5.97	7.125	1.194	0.025	2.717 2.697	0.020	
Nov 10 to Nov 19	9.09	9.188	1.011	0.040	2.697 2.663	0.034	
Nov 19 to Nov 24	5.07	6.031	1.189	0.032	2.663 2.638	0.025	
Nov 24 to Nov 30	5.76	6.813	1.183	0.047	2.638 2.597	0.041	
Nov 30 to Dec 01	1.08	1.281	1.186	0.007	2.718 2.715	0.003	
Dec 01 to Dec 07	6.06	7.219	1.191	0.029	2.715 2.693	0.022	
Dec 07 to Dec 16	8.99	8.781	0.977	0.021	2.693 2.676	0.017	
Dec 16 to Dec 23	6.95	8.250	1.187	0.034	2.676 2.647	0.029	
Dec 23 to Dec 30	6.95	8.219	1.182	0.015	2.647 2.633	0.014	
Dec 30 to Jan 5,1993	6.11	7.219	1.182	0.015	2.718 2.705	0.013	
Jan 05 to Jan 11	5.89	6.906	1.172	0.026	2.705 2.686	0.019	
Jan 11 to Jan 19	7.99	8.656	1.083	0.013	2.686 2.675	0.011	
Jan 19 to Jan 26	6.98	8.250	1.183	0.007	2.675 2.667	0.008	
Jan 26 to Feb 01	5.98	6.813	1.139	0.002	2.667 2.670	−0.003	Clock found stopped by consultants
Feb 01 to Feb 02	1.000	0.000	0.000	0.000	2.723 2.722	0.001	No data between Feb 1–2 clock was

TABLE E.2 WATER LEVEL RECORDER CHART ANALYSIS
GUELPH LANDFILL LYSIMETER 2

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	*Elapsed Time* (days)	*Chart Length* (inch)	*Chart Rate* (inch/day)	*Recorded Change* (metre)	*Field Measured Water Level* (metre)	*Water Level Change* (metre)	*Comments and Observations*
Feb 02 to Feb 09	7.01	8.375	1.195	–0.001	2.722 2.723	–0.001	stopped
Feb 09 to Feb 15	6.04	7.219	1.196	0.000	2.723 2.724	–0.001	
Feb 15 to Feb 23	7.99	9.406	1.178	–0.002	2.724 2.725	–0.001	
Feb 23 to Mar 01	5.93	7.063	1.191	–0.001	2.725 2.725	0.000	
Mar 01 to Mar 08	7.04	8.406	1.194	0.000	2.725 2.728	–0.003	
Mar 08 to Mar 17	8.98	9.531	1.061	0.000	2.728 2.727	0.001	
Mar 17 to Mar 23	6.02	7.188	1.193	–0.001	2.727 2.727	0.000	
Mar 23 to Mar 31	8.00	9.469	1.184	0.002	2.727 2.727	0.000	
Mar 31 to Mar 31	0.15	0.188	1.227	0.000	2.727 2.734	–0.007	
Mar 23 to Mar 31	8.00	9.469	1.184	0.000	2.727 2.727	0.000	
Mar 31 to Apr 07	6.86	8.188	1.193	0.003	2.734 2.732	0.002	
Apr 07 to Apr 13	6.02	7.219	1.200	0.005	2.732 2.726	0.006	
Apr 13 to Apr 20	6.96	8.344	1.199	0.038	2.726 2.695	0.031	
Apr 20 to Apr 27	7.11	8.531	1.199	0.094	2.695 2.618	0.077	
Apr 27 to Apr 30	2.95	3.531	1.195	0.028	2.618 2.598	0.020	
Apr 30 to May 03	2.95	3.531	1.195	0.033	2.726 2.705	0.021	
May 03 to May 10	6.91	8.281	1.198	0.033	2.705 2.677	0.028	
May 10 to May 17	7.01	8.406	1.199	0.016	2.677 2.666	0.011	
May 17 to May 25	7.99	9.531	1.193	0.009	2.666 2.660	0.006	
May 25 to May 31	6.10	7.344	1.204	0.004	2.660 2.655	0.005	

TABLE E.2 WATER LEVEL RECORDER CHART ANALYSIS

GUELPH LANDFILL LYSIMETER 2

Water Level Recorder: F–Type — 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	*Elapsed Time* (days)	*Chart Length* (inch)	*Chart Rate* (inch/day)	*Recorded Change* (metre)	*Field Measured Water Level* (metre)	*Water Level Change* (metre)	*Comments and Observations*
May 31 to May 31	0.09	0.094	1.098	0.000	2.655 2.655	0.000	
May 31 to Jun 07	6.78	8.125	1.199	0.004	2.726 2.722	0.004	
Jun 07 to Jun 14	6.99	8.344	1.194	0.004	2.722 2.716	0.006	
Jun 14 to Jun 21	7.03	8.406	1.195	0.005	2.716 2.712	0.004	
Jun 21 to Jun 28	7.08	8.500	1.200	0.023	2.712 2.692	0.020	
Jun 28 to Jun 30	2.12	2.563	1.209	0.006	2.692 2.688	0.004	
Jun 30 to Jul 06	5.76	n/a	n/a	n/a	2.726 2.715	0.011	Consultants did not reset chart after pumping.
Jul 06 to Jul 12	5.97	7.125	1.193	0.007	2.715 2.711	0.004	
Jul 12 to Jul 19	6.99	8.375	1.198	0.006	2.711 2.707	0.004	
Jul 19 to Jul 27	8.01	9.563	1.193	0.004	2.707 2.703	0.004	
Jul 27 to Jul 29	2.07	2.500	1.206	0.002	2.703 2.702	0.001	
Jul 29 to Aug 03	0.99	n/a	n/a	n/a	2.726 2.722	0.004	Consultants did not reset chart after pumping.
Aug 03 to Aug 09	6.02	7.250	1.204	0.004	2.722 2.716	0.006	
Aug 09 to Aug 17	7.99	9.563	1.197	0.003	2.716 2.716	0.000	
Aug 17 to Aug 23	5.97	7.125	1.194	0.002	2.716 2.715	0.001	
Aug 23 to Aug 30	7.15	8.625	1.207	0.001	2.715 2.711	0.004	
Aug 30 to Aug 31	0.99	0.938	0.943	0.000	2.711 2.713	0.002	
Aug 31 to Sep 07	7.05	8.500	1.206	0.002	2.724 2.722	0.002	
Sep 07 to Sep 13	6.00	7.188	1.198	−0.002	2.722 2.724	0.001	
Sep 13 to Sep 20	6.93	8.313	1.199	−0.002	2.724 2.726	0.001	

TABLE E.2 WATER LEVEL RECORDER CHART ANALYSIS

GUELPH LANDFILL LYSIMETER 2

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	*Elapsed Time* (days)	*Chart Length* (inch)	*Chart Rate* (inch/day)	*Recorded Change* (metre)	*Field Measured Water Level* (metre)	*Water Level Change* (metre)	*Comments and Observations*
Sep 20 to Sep 27	7.08	8.500	1.201	0.003	2.726 2.723	0.002	
Sep 27 to Oct 01	3.90	4.625	1.185	0.002	2.723 2.721	0.000	Harmony pump–out Oct 01/93 – 17 L
Oct 01 to Oct 04	3.03	3.625	1.198	–0.002	2.723 2.725	0.002	
Oct 04 to Oct 12	8.06	9.500	1.178	–0.003	2.725 2.728	0.001	
Oct 12 to Oct 20	8.02	9.50	1.185	0.003	2.728 2.725	0.002	
Oct 20 to Oct 25	4.91	5.875	1.196	0.000	2.725 2.725	0.000	
Oct 25 to Nov 01	6.95	8.500	1.222	0.004	2.725 2.721	0.003	Harmony pump–out Nov 01/93 – 5 L
Nov 01 to Nov 08	7.04	8.500	1.207	0.002	2.722 2.720	0.002	
Nov 08 to Nov 15	6.97	8.313	1.193	0.000	2.720 2.720	0.002	
Nov 15 to Nov 22	7.04	8.250	1.172	0.005	2.720 2.715	0.003	
Nov 22 to Nov 29 +	6.94	8.313	1.198	0.005	2.715 2.710	0.012	

TABLE E.3 WATER LEVEL RECORDER CHART ANALYSIS
GUELPH LANDFILL LYSIMETER 3

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/chart : 0.3 inches/day

Period	Elapsed Time (days)	Chart Length (inch)	Chart Rate (inch/day)	Recorded Change (metre)	Field Measured Water Level (metre)	Water Level Change (metre)	Comments and Observations
Sep 30,1991 to Oct 31	31.00	9.313	0.300	–0.002	2.707	NA	
Oct 31 to Nov 26	26.21	7.875	0.300	0.007	2.707 2.703	0.004	
Nov 26 to Nov 28	1.84	0.563	0.305	0.005	2.703 2.696	0.007	
Nov 28 to Dec 6	7.95	NA	NA	0.038	2.704 2.670	0.034	ran out of room on chart
Dec 06 to Feb 24,1992	80.000	NA	NA	NA	NA	NA	Recorder removed Dec 06 replaced Feb 24 set to 8 day chart
Feb 24 to Mar 02	6.94	8.063	1.162	0.003	2.690 2.688	0.002	Datum change Feb 27 Pumpout Mar 2
Mar 02 to Mar 09	6.83	8.188	1.198	0.003	2.709 2.706	0.003	
Mar 09 to Mar 16	7.04	NA	NA	NA	2.706 2.704	0.002	Clock stopped
Mar 16 to Mar 23	6.90	NA	NA	NA	2.704 2.699	0.005	Clock stopped
Mar 23 to Mar 30	7.00	NA	NA	NA	2.699 2.697	0.002	Clock stopped
Mar 30 to Apr 01	1.96	NA	NA	NA	2.697 2.697	0.000	Clock stopped Pumpout Apr 1
Apr 03 to Apr 14	11.00	NA	NA	NA	2.708 2.706	0.002	No recorder present in for repairs
Apr 14 to Apr 21	7.08	8.563	1.209	0.019	2.706 2.690	0.016	
Apr 21 to Apr 28	6.98	8.406	1.204	0.020	2.690 2.672	0.018	
Apr 28 to May 01	2.88	3.500	1.217	0.008	2.672 2.667	0.005	
May 01 to May 05	4.08	4.938	1.209	0.012	2.710 2.699	0.011	
May 05 to May 12	7.02	8.438	1.202	0.014	2.699 2.690	0.009	
May 12 to May 19	6.98	8.438	1.209	0.010	2.690 2.681	0.009	
May 19 to May 27	7.94	9.500	1.197	0.013	2.681 2.673	0.008	
May 27 to May 29	1.96	2.344	1.197	0.002	2.673 2.668	0.005	

TABLE E.3 WATER LEVEL RECORDER CHART ANALYSIS
GUELPH LANDFILL LYSIMETER 3

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/chart : 0.3 inches/day

Period	*Elapsed Time* (days)	*Chart Length* (inch)	*Chart Rate* (inch/day)	*Recorded Change* (metre)	*Field Measured Water Level* (metre)	*Water Level Change* (metre)	*Comments and Observations*
May 29 to Jun 02	4.01	4.875	1.216	0.004	2.710 2.712	−0.002	
Jun 02 to Jun 10	8.03	9.563	1.191	0.006	2.712 2.706	0.006	
Jun 10 to Jun 18	7.98	9.500	1.191	0.004	2.706 2.705	0.001	
Jun 18 to Jun 24	6.00	7.250	1.208	0.004	2.705 2.700	0.005	
Jun 24 to Jun 30	5.96	7.188	1.206	0.002	2.700 2.696	0.004	
Jun 30 to Jul 07	7.00	8.438	1.205	0.001	2.714 2.714	0.000	
Jul 07 to Jul 15	7.99	9.469	1.185	0.003	2.714 2.712	0.002	
Jul 15 to Jul 21	6.04	7.250	1.200	0.008	2.712 2.705	0.007	
Jul 21 to Jul 29	7.96	9.469	1.190	0.010	2.705 2.695	0.010	
Jul 29 to Jul 31	2.09	2.500	1.194	0.002	2.695 2.693	0.002	
Jul 31 to Aug 05	4.92	5.938	1.208	0.003	2.711 2.706	0.005	
Aug 05 to Aug 11	6.01	7.281	1.211	0.008	2.706 2.701	0.005	
Aug 11 to Aug 19	7.99	9.500	1.189	0.013	2.701 2.689	0.012	
Aug 19 to Aug 25	5.99	7.250	1.210	0.008	2.689 2.685	0.004	
Aug 25 to Aug 31	6.11	7.406	1.211	0.008	2.685 2.676	0.009	
Aug 31 to Sep 02	1.85	2.000	1.079	0.005	2.711 2.708	0.003	
Sep 02 to Sep 08	6.04	7.313	1.210	0.008	2.708 2.701	0.007	
Sep 08 to Sep 15	6.89	8.313	1.207	0.011	2.701 2.694	0.007	
Sep 15 to Sep 24	9.13	9.531	1.044	0.012	2.694 2.683	0.011	
Sep 24 to Oct 01	7.06	8.375	1.186	0.010	2.683 2.674	0.009	

TABLE E.3 WATER LEVEL RECORDER CHART ANALYSIS
GUELPH LANDFILL LYSIMETER 3

Water Level Recorder: F–Type — 8 days/chart : 1.2 inches/day
32 days/chart : 0.3 inches/day

Period	*Elapsed Time* (days)	*Chart Length* (inch)	*Chart Rate* (inch/day)	*Recorded Change* (metre)	*Field Measured Water Level* (metre)	*Water Level Change* (metre)	*Comments and Observations*
Oct 01 to Oct 08	6.82	8.219	1.205	0.007	2.710 2.705	0.005	
Oct 08 to Oct 16	7.98	9.563	1.198	0.008	2.705 2.699	0.006	
Oct 16 to Oct 22	6.14	7.359	1.199	0.013	2.699 2.689	0.010	
Oct 22 to Oct 30	7.85	9.438	1.202	0.025	2.689 2.673	0.016	Ran out of room on chart
Oct 30 to Nov 02	3.19	3.813	1.196	0.009	2.673 2.665	0.008	
Nov 02 to Nov 04	1.82	2.156	1.183	0.006	2.710 2.704	0.006	
Nov 04 to Nov 10	5.98	7.188	1.202	0.017	2.704 2.690	0.014	
Nov 10 to Nov 19	9.09	8.906	0.980	0.026	2.690 2.664	0.026	
Nov 19 to Nov 24	5.07	6.094	1.201	0.019	2.664 2.648	0.016	
Nov 24 to Nov 30	5.75	6.906	1.202	0.021	2.648 2.629	0.019	
Nov 30 to Dec 1	1.09	1.313	1.204	0.006	2.706 2.705	0.001	
Dec 1 to Dec 7	6.07	7.250	1.195	0.021	2.705 2.687	0.018	
Dec 7 to Dec 16	9.00	8.406	0.934	0.021	2.687 2.665	0.022	
Dec 16 to Dec 23	6.93	8.250	1.190	0.026	2.665 2.640	0.025	
Dec 23 to Dec 30	6.94	8.281	1.193	0.012	2.640 2.628	0.012	
Dec 30 to Jan 5,1993	6.10	7.313	1.199	0.013	2.706 2.695	0.011	
Jan 5 to Jan 11	5.88	7.031	1.195	0.010	2.695 2.687	0.008	
Jan 11 to Jan 19	7.99	9.125	1.142	0.009	2.687 2.678	0.009	
Jan 19 to Jan 26	6.97	8.406	1.206	0.006	2.678 2.678	0.000	
Jan 26 to Feb 01	5.90	7.125	1.208	0.005	2.678 2.669	0.009	

TABLE E.3 WATER LEVEL RECORDER CHART ANALYSIS
GUELPH LANDFILL LYSIMETER 3

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/chart : 0.3 inches/day

Period	*Elapsed Time* (days)	*Chart Length* (inch)	*Chart Rate* (inch/day)	*Recorded Change* (metre)	*Field Measured Water Level* (metre)	*Water Level Change* (metre)	*Comments and Observations*
Feb 01 to Feb 02	1.03	1.250	1.208	0.000	2.710 2.710	0.000	
Feb 02 to Feb 09	7.01	8.406	1.199	−0.001	2.710 2.711	−0.001	
Feb 09 to Feb 15	6.04	7.250	1.201	0.001	2.711 2.708	0.003	
Feb 15 to Feb 23	7.99	9.438	1.181	−0.001	2.708 2.710	−0.002	
Feb 23 to Mar 01	5.93	7.188	1.211	−0.002	2.710 2.712	−0.002	
Mar 01 to Mar 08	7.04	8.531	1.212	0.000	2.712 2.711	0.001	
Mar 08 to Mar 17	8.98	9.594	1.068	−0.001	2.711 2.713	−0.002	
Mar 17 to Mar 23	6.02	7.281	1.209	−0.001	2.713 2.715	−0.002	
Mar 23 to Mar 31	8.00	9.156	1.145	0.002	2.715 2.715	0.000	
Mar 23 to Mar 31	0.16	0.156	0.978	0.000	2.715 2.715	0.000	
Mar 31 to Apr 07	6.85	8.250	1.204	0.002	2.727 2.728	−0.001	
Apr 07 to Apr 13	6.02	7.313	1.215	0.009	2.728 2.721	0.007	
Apr 13 to Apr 20	6.96	8.453	1.214	0.018	2.721 2.704	0.017	
Apr 20 to Apr 27	7.13	8.594	1.205	0.023	2.704 2.687	0.017	
Apr 27 to Apr 30	2.95	3.594	1.218	0.009	2.687 2.675	0.012	
Apr 30 to May 03	2.95	3.563	1.207	0.022	2.726 2.713	0.013	
May 03 to May 10	6.91	8.375	1.212	0.017	2.713 2.703	0.010	
May 10 to May 17	7.01	8.531	1.217	0.012	2.703 2.699	0.004	
May 17 to May 25	7.99	9.625	1.204	0.007	2.699 2.688	0.011	
May 25 to May 31	6.09	7.375	1.211	0.004	2.688 2.684	0.004	

TABLE E.3 WATER LEVEL RECORDER CHART ANALYSIS
GUELPH LANDFILL LYSIMETER 3

Water Level Recorder: F–Type — 8 days/chart : 1.2 inches/day
32 days/chart : 0.3 inches/day

Period	*Elapsed Time* (days)	*Chart Length* (inch)	*Chart Rate* (inch/day)	*Recorded Change* (metre)	*Field Measured Water Level* (metre)	*Water Level Change* (metre)	*Comments and Observations*
May 31 to May 31	0.09	0.094	1.000	0.000	2.684 2.685	−0.001	
May 31 to Jun 07	6.77	8.188	1.209	0.003	2.730 2.727	0.003	
Jun 07 to Jun 14	6.99	8.469	1.211	0.004	2.727 2.719	0.008	
Jun 14 to Jun 21	7.04	8.500	1.207	0.005	2.719 2.717	0.002	
Jun 21 to Jun 28	7.07	8.594	1.216	0.015	2.717 2.705	0.012	
Jun 28 to Jun 30	2.13	2.594	1.219	0.005	2.705 2.699	0.006	Pump 230 L
Jun 30 to Jul 06	5.76	6.969	1.210	0.008	2.729 2.720	0.009	
Jul 06 to Jul 12	6.08	7.094	1.167	0.007	2.720 2.718	0.002	
Jul 12 to Jul 19	7.08	8.438	1.191	0.009	2.718 2.713	0.005	
Jul 19 to Jul 27	8.05	9.625	1.196	0.005	2.713 2.710	0.003	
Jul 27 to Jul 29	3.02	2.563	0.849	0.004	2.710 2.708	0.002	
Jul 29 to Aug 03	5.02	5.938	1.183	0.007	2.729 2.721	0.008	
Aug 03 to Aug 09	6.12	7.313	1.195	0.004	2.721 2.720	0.001	
Aug 09 to Aug 17	8.13	9.563	1.176	0.005	2.720 2.714	0.006	
Aug 17 to Aug 23	6.09	7.238	1.189	0.003	2.714 2.713	0.001	
Aug 23 to *Aug 30*	7.13	8.625	1.209	*0.003*	2.713 *2.710*	*0.000*	
Aug 30 to Aug 31	0.88	1.000	1.142	−0.004	2.710 2.714	0.001	
Aug 31 to Sep 07	7.10	8.438	1.189	0.006	2.729 2.723	0.002	
Sep 07 to Sep 13	5.48	7.250	1.323	−0.004	2.723 2.727	0.001	
Sep 13 to Sep 20	6.94	8.375	1.207	−0.001	2.727 2.728	0.001	

TABLE E.3 WATER LEVEL RECORDER CHART ANALYSIS
GUELPH LANDFILL LYSIMETER 3

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/chart : 0.3 inches/day

Period	*Elapsed Time* (days)	*Chart Length* (inch)	*Chart Rate* (inch/day)	*Recorded Change* (metre)	*Field Measured Water Level* (metre)	*Water Level Change* (metre)	*Comments and Observations*
Sep 20 to Sep 27	7.069	8.563	1.211	0.005	2.728 2.723	0.002	
Sep 27 to Oct 01	3.91	4.688	1.200	−0.003	2.723 2.726	0.000	Harmony pump–out Oct 01/93 – 9 L
Oct 01 to Oct 04	3.94	3.625	0.921	−0.001	2.729 2.730	0.000	
Oct 04 to Oct 12	8.07	9.625	1.193	−0.002	2.730 2.732	0.001	
Oct 12 to Oct 20	8.03	9.625	1.199	−0.007	2.723 2.730	0.002	
Oct 20 to Oct 25	4.94	6.000	1.215	0.012	2.730 2.718	0.016	
Oct 25 to Nov 01	7.00	8.438	1.205	0.024	2.718 2.694	0.022	Harmony pump–out Nov 01/93 – 222 L
Nov 01 to Nov 08	7.04	8.500	1.208	0.017	2.725 2.708	0.019	
Nov 08 to Nov 15	6.97	8.500	1.220	0.011	2.708 2.697	0.012	
Nov 15 to *Nov 22*	7.04	8.563	1.216	*0.027*	2.697 *2.670*	*0.020*	
Nov 22 to Nov 29 +	6.94	8.375	1.207	0.032	2.670 2.638	0.035	

TABLE E.4 WATER LEVEL RECORDER CHART ANALYSIS
BARRIE LANDFILL LYSIMETER 1

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	Elapsed Time (days)	Chart Length (inch)	Chart Rate (inch/day)	Recorded Change (metre)	Field Measured Water Level (metre)	Water Level Change (metre)	Comments and Observations
Feb 26, 1992 to Feb 28	1.93	2.250	1.168	0.002	3.380 3.380	0.000	Pumpout Feb 28
Mar 02 to Mar 09	7.07	7.125	1.007	0.002	3.416 3.414	0.002	
Mar 09 to Mar 16	7.07	8.250	1.166	0.010	3.414 3.406	0.008	
Mar 16 to Mar 23	6.90	8.250	1.196	0.008	3.406 3.401	0.005	
Mar 23 to Mar 30	7.00	8.375	1.196	0.005	3.401 3.397	0.004	
Mar 30 to Apr 01	1.83	2.250	1.227	0.001	3.397 3.397	0.000	Pumpout Apr 1
Apr 03 to Apr 14	11.07	NA	NA	0.003	3.418 3.415	0.003	Chart paper did not move
Apr 14 to Apr 21	6.78	8.125	1.198	0.038	3.415 3.382	0.033	
Apr 21 to Apr 28	7.00	NA	NA	NA	3.382 3.359	0.023	Chart paper did not move
Apr 28 to May 01	3.15	3.750	1.192	0.012	3.359 3.350	0.009	
May 01 to May 05	3.85	4.250	1.103	0.008	3.422 3.414	0.008	
May 05 to May 12	6.96	8.313	1.195	0.007	3.414 3.408	0.006	
May 12 to May 19	6.98	8.313	1.191	0.009	3.408 3.403	0.005	
May 19 to May 27	7.98	9.375	1.175	0.007	3.403 3.396	0.007	
May 27 to May 29	2.03	2.375	1.169	0.002	3.396 3.395	0.001	consultant pump date is shown to occur on may 30, it actually ocurred on 29/05/91.
May 29 to Jun 02	3.94	4.688	1.191	0.005	3.415 3.413	0.002	
Jun 02 to Jun 10	8.02	9.375	1.169	0.006	3.413 3.407	0.006	
Jun 10 to Jun 18	7.99	9.313	1.166	0.006	3.407 3.404	0.003	
Jun 18 to Jun 24	6.01	7.125	1.185	0.004	3.404 3.399	0.005	
Jun 24 to Jun 30	5.99	5.813	0.971	0.003	3.399 3.398	0.001	
Jun 30 to	2.02	2.344	1.160	0.000	3.398	0.000	

TABLE E.4 WATER LEVEL RECORDER CHART ANALYSIS
BARRIE LANDFILL LYSIMETER 1

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	Elapsed Time (days)	Chart Length (inch)	Chart Rate (inch/day)	Recorded Change (metre)	Field Measured Water Level (metre)	Water Level Change (metre)	Comments and Observations
Jul 02					3.398		
Jul 02 to Jul 07	4.99	5.875	1.177	0.002	3.418 3.416	0.002	
Jul 07 to Jul 15	7.99	9.375	1.173	0.003	3.416 3.412	0.004	
Jul 15 to Jul 21	6.01	7.125	1.185	0.002	3.412 3.410	0.002	
Jul 21 to Jul 29	7.99	9.375	1.173	0.003	3.410 3.408	0.002	
Jul 29 to Aug 05	7.01	8.375	1.195	0.002	3.408 3.407	0.001	
Aug 05 to Aug 11	6.00	7.125	1.188	0.006	3.407 3.403	0.004	
Aug 11 to Aug 19	7.99	9.375	1.174	0.004	3.403 3.397	0.006	
Aug 19 to Aug 25	6.00	NA	NA	NA	3.397 3.394	0.003	Chart recorder not functioning
Aug 25 to Sep 01	7.00	8.094	1.156	0.013	3.394 3.383	0.011	
Sep 02 to Sep 08	6.03	6.688	1.109	0.014	3.415 3.405	0.010	
Sep 08 to Sep 15	7.15	8.438	1.181	0.013	3.405 3.396	0.009	
Sep 15 to Sep 24	8.84	9.250	1.046	0.007	3.396 3.390	0.006	
Sep 24 to Sep 30	6.18	7.313	1.184	0.006	3.390 3.384	0.006	
Sep 30 to Oct 02	1.79	0.531	0.297	0.002	3.384 3.383	0.001	Recorder changed to thirty two days period.
Oct 02 to Oct 28	26.11	7.813	0.299	0.024	3.418 3.401	0.017	Chart not reset properly by the consultants
Oct 28 to Oct 30	1.96	0.594	0.303	0.004	3.401 3.397	0.004	
Oct 30 to Nov 25	25.93	7.875	0.304	0.153	3.418 3.296	0.122	Chart not reset properly by the consultants
Nov 25 to Dec 01	5.96	1.781	0.299	0.032	3.296 3.268	0.028	
Dec 01 to Dec 29	27.99	7.313	0.261	0.095	3.416 3.353	0.063	
Dec 29 to Jan 04,1993	5.95	1.563	0.263	0.021	3.353 3.335	0.018	

TABLE E.4 WATER LEVEL RECORDER CHART ANALYSIS
BARRIE LANDFILL LYSIMETER 1

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	Elapsed Time (days)	Chart Length (inch)	Chart Rate (inch/day)	Recorded Change (metre)	Field Measured Water Level (metre)	Water Level Change (metre)	Comments and Observations
Jan 04 to Jan 27	22.90	0.000	0.000	0.081	3.416 3.344	0.072	Recorder not working
Jan 27 to Feb 02	4.97	0.000	0.000	0.000	3.344 3.337	0.007	Recorder not working
Feb 02 to Feb 04	1.93	0.000	0.000	0.001	3.416 3.415	0.001	Recorder not working
Feb 04 to Mar 02	25.990	n/a	n/a	n/a	3.415 3.400	0.015	Recorder not working Dismantled for repairs
Mar 02 to Mar 24	21.965	n/a	n/a	n/a	3.400 3.398	n/a	
Mar 24 to Mar 29	4.000	n/a	n/a	n/a	3.398 3.189	n/a	
May 03 to May 03	0.030	n/a	n/a	n/a	3.240 3.416	n/a	
Jun 01 to Jun 01	0.013	1.000	76.923	−0.040	3.380 3.420	n/a	
Jun 01 to Jun 30	29.921	1.188	0.040	0.028	3.420 3.392	n/a	
Jun 30 to Jul 29	29.031	n/a	n/a	0.042	3.415 3.373	n/a	
Jul 29 to Jul 30	1.158	0.375	0.324	−0.002	3.372 3.374	0.002	
Jul 30 to Aug 06	5.837	2.000	0.343	0.005	3.415 3.410	0.006	
Aug 06 to Aug 26	20.024	5.938	0.297	0.014	3.410 3.396	0.016	
Aug 26 to Sep 02	7.044	2.125	0.302	0.004	3.396 3.392	0.006	
Sep 02 to Sept 29	26.938	7.750	0.288	0.040	3.415 3.375	0.043	
Sept 29 to Oct 01	1.972	0.875	0.444	0.005	3.375 3.370	0.010	
Oct 01 to Oct 28	28.014	8.188	0.292	0.054	3.419 3.365	0.056	
Oct 28 to Nov 01	3.958	1.188	0.300	0.002	3.365 3.363	0.005	
Nov 01 to Nov 25	23.951	7.250	0.303	0.012	3.415 3.403	0.019	Lys. clocks were removed Nov. 25/93

TABLE E.5 WATER LEVEL RECORDER CHART ANALYSIS
BARRIE LANDFILL LYSIMETER 2

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	Elapsed Time (days)	Chart Length (inch)	Chart Rate (inch/day)	Recorded Change (metre)	Field Measured Water Level (metre)	Water Level Change (metre)	Comments and Observations
Feb 26, 1992 to Feb 28	1.92	2.313	1.204	0.001	3.382 3.385	−0.003	Pumpout Feb 28
Mar 02 to Mar 09	7.12	NA	NA	0.002	3.412 3.409	0.003	Clock stopped
Mar 09 to Mar 16	7.08	8.250	1.165	0.021	3.409 3.393	0.016	
Mar 16 to Mar 23	6.88	8.250	1.200	0.006	3.393 3.389	0.004	
Mar23 to Mar 30	7.00	8.375	1.196	0.003	3.389 3.386	0.003	
Mar 30 to Apr 01	1.86	2.219	1.192	0.001	3.386 3.385	0.001	Pumpout Apr 1
Apr 03 to Apr 14	11.06	NA	NA	0.003	3.405 3.403	0.002	Recorder left 11 days
Apr 14 to Apr 21	6.78	8.125	1.198	0.002	3.403 3.401	0.002	
Apr 21 to Apr 28	7.00	6.438	0.920	0.010	3.401 3.394	0.007	
Apr 28 to May 01	3.15	3.750	1.192	0.008	3.394 3.388	0.006	
May 01 to May 05	3.82	4.563	1.195	0.008	3.411 3.404	0.007	
May 05 to May 12	6.96	8.250	1.186	0.010	3.404 3.396	0.008	
May 12 to May 19	7.01	8.375	1.195	0.006	3.396 3.391	0.005	
May 19 to May 27	7.99	9.375	1.174	0.007	3.391 3.386	0.005	
May 27 to May 29	2.04	2.438	1.194	0.001	3.386 3.385	0.001	consultant pump date is shown to occur on May 30, it actually ocurred on 29/05/91
May 29 to Jun 02	3.90	4.656	1.195	0.003	3.411 3.409	0.002	
Jun 02 to Jun 10	8.02	9.313	1.161	0.007	3.409 3.404	0.005	
Jun 10 to Jun 18	7.99	9.281	1.162	0.007	3.404 3.401	0.003	
Jun 18 to Jun 24	6.01	7.156	1.191	0.005	3.401 3.397	0.004	
Jun 24 to Jun 30	5.99	6.938	1.158	0.003	3.397 3.397	0.000	
Jun 30 to	1.99	2.344	1.175	0.001	3.397	0.002	

TABLE E.5 WATER LEVEL RECORDER CHART ANALYSIS
BARRIE LANDFILL LYSIMETER 2

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	Elapsed Time (days)	Chart Length (inch)	Chart Rate (inch/day)	Recorded Change (metre)	Field Measured Water Level (metre)	Water Level Change (metre)	Comments and Observations
Jul 02					3.395		
Jul 02 to Jul 07	4.96	5.875	1.185	0.002	3.397 3.394	0.003	
Jul 07 to Jul 15	7.99	9.313	1.166	0.002	3.394 3.392	0.002	
Jul 15 to Jul 21	6.00	7.125	1.188	0.003	3.392 3.390	0.002	
Jul 21 to Jul 29	7.99	9.344	1.170	0.004	3.390 3.388	0.002	
Jul 29 to Aug 05	7.01	8.344	1.190	0.001	3.388 3.386	0.002	
Aug 05 to Aug 11	5.86	6.969	1.188	0.001	3.411 3.410	0.001	
Aug 11 to Aug 19	8.00	9.344	1.168	0.003	3.410 3.410	0.000	
Aug 19 to Aug 25	6.00	NA	NA	NA	3.410 3.409	0.001	Clock malfunction
Aug 25 to Sep 01	7.00	8.406	1.201	0.000	3.409 3.405	0.004	
Sep 01 to Sep 02	0.96	0.934	0.975	0.001	3.405 3.405	0.000	
Sep 02 to Sep 08	6.03	7.188	1.192	0.003	3.405 3.405	0.000	
Sep 08 to Sep 15	7.13	8.500	1.193	0.003	3.405 3.404	0.001	
Sep 15 to Sep 24	8.83	9.250	1.047	0.006	3.404 3.400	0.004	
Sep 24 to Sep 30	6.17	7.344	1.191	0.003	3.400 3.398	0.002	
Sep 30 to Oct 02	1.85	0.563	0.303	0.002	3.398 3.395	0.003	Recorder changed to thirty two days period.
Oct 02 to Oct 28	26.10	7.750	0.297	0.008	3.395 3.393	0.002	
Oct 28 to Oct 30	2.00	0.594	0.297	0.001	3.393 3.390	0.003	
Oct 30 to Nov 25	25.90	7.688	0.297	0.025	3.413 3.392	0.021	
Nov 25 to Dec 01	5.99	1.750	0.292	0.012	3.392 3.382	0.010	
Dec 01 to Dec 29	27.98	7.531	0.269	0.024	3.403 3.380	0.023	

TABLE E.5 WATER LEVEL RECORDER CHART ANALYSIS

BARRIE LANDFILL LYSIMETER 2

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

Period	Elapsed Time (days)	Chart Length (inch)	Chart Rate (inch/day)	Recorded Change (metre)	Field Measured Water Level (metre)	Water Level Change (metre)	Comments and Observations
Dec 29 to Jan 04,1993	5.97	0.375	0.063	0.003	3.380 3.377	0.003	
Jan 04 to Jan 27	22.88	n/a	0.000	0.018	3.410 3.389	0.021	
Jan 27 to Feb 02	6.03	1.125	0.187	0.003	3.389 3.387	0.002	
Feb 02 to Feb 04	1.94	0.281	0.145	0.003	3.410 3.408	0.002	
Feb 04 to Feb 24	19.93	5.531	0.278	0.009	3.408 3.406	0.002	
Feb 24 to Mar 02	6.06	1.750	0.289	0.003	3.406 3.405	0.001	
Mar 02 to Mar 24	21.92	6.594	0.301	0.004	3.405 3.399	0.006	
Mar 24 to Mar 29	5.01	1.469	0.293	0.002	3.399 3.394	0.005	
Mar 29 to Apr 27	29.00	8.500	0.293	0.031	3.394 3.360	0.034	
Apr 27 to May 03	6.04	1.781	0.295	0.008	3.360 3.355	0.005	
May 03 to May 26	22.86	6.766	0.296	0.021	3.410 3.388	0.022	
May 26 to Jun 01	5.98	1.766	0.295	0.003	3.388 3.386	0.002	
Jun 01 to Jun 29	27.974	8.188	0.293	0.015	3.410 3.397	0.013	
Jun 29 to Jun 30	0.894	0.250	0.280	−0.001	3.397 3.398	0.000	
Jun 30 to Jul 29	29.008	8.688	0.299	0.016	3.415 3.399	0.016	
Jul 29 to	1.184	0.375	0.317	NA	3.399		
Jul 30 to Aug 26	26.917	8.000	0.297	0.011	3.415 3.404	0.013	
Aug 26 to Sep 02	6.469	2.063	0.319	0.004	3.404 3.400	0.004	
Sep 02 to Sep 29	26.972	7.563	0.280	0.008	3.415 3.407	0.008	
Sep 29 to Oct 01	2.038	0.563	0.276	0.000	3.407 3.407	0.000	

TABLE E.5 WATER LEVEL RECORDER CHART ANALYSIS
BARRIE LANDFILL LYSIMETER 2

Water Level Recorder: F–Type – 8 days/chart : 1.2 inches/day
32 days/ chart : 0.3 inches/day

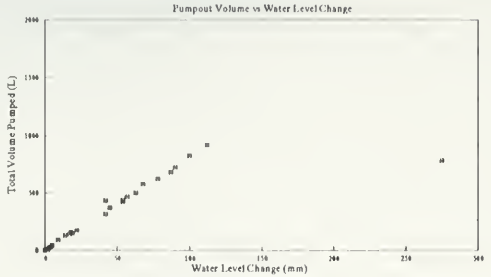
Period	Elapsed Time (days)	Chart Length (inch)	Chart Rate (inch/day)	Recorded Change (metre)	Field Measured Water Level (metre)	Water Level Change (metre)	Comments and Observations
Oct 01 to Oct 28	27.035	8.125	0.301	0.014	3.415 3.401	0.015	
Oct 28 to Nov 01	3.986	1.125	0.282	0.001	3.401 3.400	0.003	
Nov 01 to Nov 25	23.903	7.063	0.295	0.011	3.415 3.404	0.010	Note: Lys. clocks were removed Nov.25/93

TABLE E6. PUMPOUT VOLUME VS. WATER LEVEL CHANGE
GUELPH LANDFILL
(November '91 – October '94)

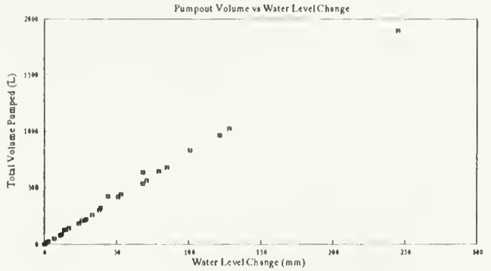
	LYSIMETER #1		LYSIMETER #2		LYSIMETER #3	
Pumpout Period	Total Volume Pumped (L)	Water Level Change (mm)	Total Volume Pumped (L)	Water Level Change (mm)	Total Volume Pumped (L)	Water Level Change (mm)
Oct. 31 – Nov. 26, 1991	0.0	**−2.0**	0.0	0.0	0.0	−4.0
Nov. 27 – Dec. 31	680.0	87.0	535.0	68.0	938.0	113.0
Jan. 01 – Jan. 30, 1992	621.0	78.0	641.0	79.0	762.0	92.0
Jan. 31 – Mar. 02	46.0	5.0	86.0	12.0	174.0	21.0
Mar. 03 – Apr. 01	0.0	**−2.0**	0.0	−1.0	103.0	12.0
Apr. 02 – May 01	827.0	100.0	829.0	101.0	355.0	43.0
May 02 – May 29	575.0	68.0	420.0	51.0	339.0	42.0
May 30 – Jun. 30	140.0	17.0	124.0	15.0	123.0	15.0
Jul. 01 – Jul. 31	440.0	54.0	130.0	14.0	128.0	18.0
Aug. 01 – Aug. 31	495.0	63.0	205.0	26.0	267.0	35.0
Sep. 01 – Oct. 01	316.0	42.0	320.0	39.0	291.0	36.0
Oct. 02 – Nov. 02	422.0	54.0	422.0	44.0	382.0	45.0
Nov. 03 – Nov. 30	915.0	112.0	960.0	121.0	630.0	77.0
Dec. 01 – Dec. 30	430.0	42.0	676.0	85.0	632.0	78.0
Dec. 31 – Feb. 01, 1993	369.0	45.0	438.0	53.0	340.0	41.0
Feb. 02 – Mar. 01	0.0	0.0	0.0	0.0	0.0	0.0
Mar. 02 – Mar. 31	28.0	3.0	45.0	7.0	119.0	12.0
Apr. 01 – Apr. 30	725.0	90.0	1020.0	128.0	400.0	51.0
May 01 – May 31	465.0	57.0	558.0	71.0	348.0	45.0
Jun. 01 – Jun. 30	160.0	18.0	302.0	38.0	230.0	30.0
Jul. 01 – Jul. 29	133.0	14.0	184.0	24.0	165.0	21.0
Jul. 30 – Aug. 31	90.0	9.0	79.0	11.0	128.0	15.0
Sept 01 – Oct. 01	26.0	3.0	17.0	2.0	9.0	2.0
Oct. 02 – Nov. 01	0.0	0.0	5.0	1.0	222.0	32.0
Nov. 02 – Dec. 01	0.0	**−2.0**	141.0	17.0	742.0	92.0
Dec. 02 – Dec. 30	29.0	4.0	212.0	28.0	815.0	113.0
Dec. 31 – Feb. 03, 1994	12.0	1.0	0.0	−2.0	0.0	−5.0
Feb. 04 – Feb. 28	0.0	−1.0	0.0	0.0	19.0	2.0
Mar. 01 – Apr. 04	4.0	0.0	80.0	11.0	110.0	15.0
Apr. 05 – Apr. 29	173.0	22.0	257.0	33.0	626.0	77.0
Apr. 30 – May 31	783.0	275.0	1896.0	245.0	1088.0	137.0
Jun. 01 – Jun. 30	430.0	42.0	635.0	68.0	267.0	35.0
Jul. 01 – Aug. 03	151.0	19.0	220.0	29.0	179.0	21.0
Aug. 04 – Aug 30	45.0	5.0	25.0	3.0	30.0	4.0
Aug. 31 – Sep. 30	0.0	0.0	5.0	1.0	1.0	0.0
Oct. 01 – Oct. 31	0.0	0.0	0.0	0.0	0.0	0.0

Negative values generally represent increases in well water levels that were not pumped out and have been omitted from the attached graphs. Where the negative value has been highlighted, the water level in the monitoring well actually dropped since the last pump out period.

Guelph Lysimeter 1


Pumpout Volume vs Water Level Change

Guelph Lysimeter 2


Pumpout Volume vs Water Level Change

Guelph Lysimeter 3

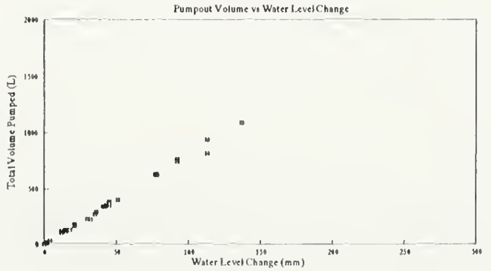

Pumpout Volume vs Water Level Change

TABLE E7. PUMPOUT VOLUME VS. WATER LEVEL CHANGE

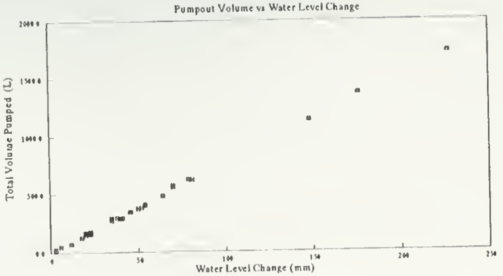
BARRIE LANDFILL

(November '91 – October '94)

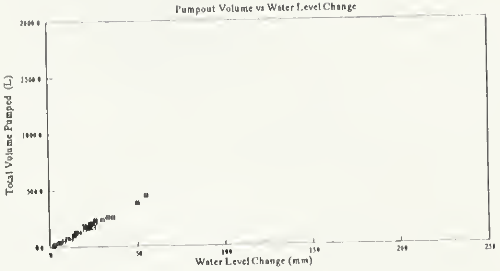
Pumpout Period	LYSIMETER #1 Total Volume Pumped (L)	LYSIMETER #1 Water Level Change (mm)	LYSIMETER #2 Total Volume Pumped (L)	LYSIMETER #2 Water Level Change (mm)	LYSIMETER #3 Total Volume Pumped (L)	LYSIMETER #3 Water Level Change (mm)
Nov. 01 – Dec. 02, 1991	165.0	20.0	0.0	–10.0	218.0	30.0
Dec. 03 – Dec. 31	570.0	70.0	381.0	50.0	295.0	33.0
Jan. 01 – Feb. 03, 1992	0.0	–20.0	0.0	–20.0	0.0	–23.0
Feb. 04 – Feb. 28	293.0	35.0	238.0	30.0	260.0	35.0
Feb. 29 – Mar. 20	0.0	–10.0	0.0	–25.0	0.0	–5.0
Mar. 21 – Apr. 01	158.0	23.0	190.0	20.0	0.0	–2.0
Apr. 02 – May 01	559.0	70.0	169.0	23.0	427.0	52.0
May 02 – May 29	170.0	20.0	235.0	26.0	237.0	26.0
May 30 – Jul. 02	149.0	20.0	8.0	2.0	0.0	–16.0
Jul. 03 – Aug. 05	0.0	–11.0	215.0	26.0	196.0	26.0
Aug. 06 – Sep. 01	271.0	35.0	0.0	–6.0	0.0	–9.0
Sep. 02 – Oct. 02	285.0	35.0	0.0	–10.0	200.0	28.0
Oct. 03 – Oct. 30	162.0	21.0	202.0	23.0	0.0	–11.0
Oct. 31 – Dec. 01	1133.0	148.0	175.0	21.0	548.0	68.0
Dec. 02 – Jan. 04, 1993	620.0	81.0	258.0	33.0	290.0	37.0
Jan. 05 – Feb. 02	625.0	79.0	180.0	23.0	420.0	53.0
Feb. 03 – Mar. 02	0.0	–16.0	0.0	–5.0	0.0	–15.0
Mar. 03 – Mar. 29	1720.0	227.0	0.0	–11.0	1340.0	119.0
Mar. 30 – May 03	1365.0	176.0	445.0	55.0	1345.0	157.0
May 04 – Jun. 01	287.0	40.0	210.0	24.0	215.0	27.0
Jun. 02 – Jun. 30	179.0	23.0	129.0	17.0	130.0	18.0
Jul. 01 – Jul. 30	295.0	41.0	154.0	20.0	95.0	15.0
Aug. 01 – Sept 02	171.0	23.0	130.0	15.0	103.0	12.0
Sept.03 – Oct. 01	348.0	45.0	53.0	8.0	160.0	19.0
Oct. 01 – Nov. 01	381.0	52.0	120.0	15.0	315.0	40.0
Nov. 02 – Dec. 01	157.0	23.0	108.0	14.0	160.0	21.0
Dec. 02 – Jan 04, 1994	406.0	54.0	156.0	20.0	250.0	33.0
Jan. 05 – Feb. 02	72.0	12.0	40.0	6.0	94.0	13.0
Feb. 03 – Feb. 28	483.0	64.0	72.0	12.0	74.0	10.0
Mar. 01 – Mar. 31	295.0	38.0	37.0	5.0	152.0	20.0
Apr. 01 – May 02	403.0	54.0	77.0	10.0	275.0	36.0
May 03 – Jun. 01	375.0	50.0	170.0	25.0	205.0	29.0
Jun. 02 – Jun. 30	347.0	46.0	258.0	36.0	339.0	42.0
Jul. 01 – Aug. 02	163.0	22.0	161.0	22.0	150.0	18.0
Aug. 03 – Sep. 01	125.0	18.0	100.0	14.0	85.0	11.0
Sep. 02 – Oct. 03	47.0	6.0	78.0	10.0	54.0	6.0
Oct. 04 – Oct. 28	24.0	3.0	26.0	3.0	15.0	2.0

Negative values generally represent increases in well water levels that were not pumped out and have been omitted from the attached graphs. Where the negative value has been highlighted, the water level in the monitoring well actually dropped since the last pump out period.

Barrie Lysimeter 1



Barrie Lysimeter 2



Barrie Lysimeter 3

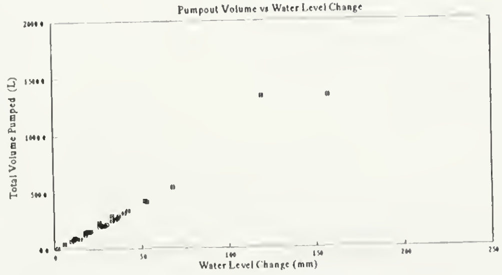


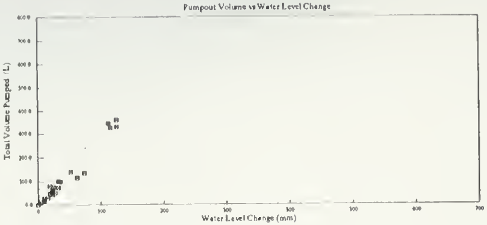
TABLE E8. PUMPOUT VOLUME VS. WATER LEVEL CHANGE
BRITANNIA ROAD LANDFILL

(November '91 – September '94)

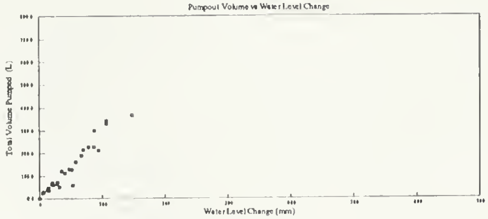
Pumpout Period	LYSIMETER #1 Total Volume Pumped (L)	LYSIMETER #1 Water Level Change (mm)	LYSIMETER #2 Total Volume Pumped (L)	LYSIMETER #2 Water Level Change (mm)	LYSIMETER #3 Total Volume Pumped (L)	LYSIMETER #3 Water Level Change (mm)	LYSIMETER #4 Total Volume Pumped (L)	LYSIMETER #4 Water Level Change (mm)
Oct. 29 – Nov. 26, 1991	0.0	**−6.0**	0.0	0.0	0.0	−3.0	0.0	−2.0
Nov. 27 – Dec. 30	0.0	−33.0	0.0	−19.0	0.0	−10.0	0.0	−12.0
Dec. 31 – Jan. 27, 1992	0.0	−25.0	216.0	70.0	0.0	−25.0	0.0	−29.0
Jan. 28 – Feb. 24	0.0	−12.0	0.0	−18.0	0.0	0.0	0.0	0.0
Feb. 25 – Mar. 24	0.0	**−7.0**	0.0	−9.0	0.0	**−29.0**	0.0	**−4.0**
Mar. 25 – Apr. 27	0.0	−22.0	228.0	79.0	252.0	305.0	0.0	−27.0
Apr. 28 – May 11	0.0	−4.0	0.0	−21.0	171.0	273.0	0.0	**−8.0**
May 12 – May 26	0.0	−10.0	61.0	22.0	94.0	46.0	0.0	**−2.0**
May 26 – Jun. 23	331.0	125.0	66.0	28.0	204.0	45.0	131.0	22.0
Jun. 24 – Jul. 27	100.0	32.0	112.0	41.0	145.0	38.0	0.0	−11.0
*Jul. 27 – Aug. 24	27.0	10.0	66.0	20.0	90.0	15.0	30.0	2.0
Aug. 25 – Sep. 24	0.0	−31.0	0.0	−29.0	0.0	−14.0	0.0	−11.0
Sep. 25 – Oct. 23	80.0	18.0	127.0	52.0	100.0	24.0	715.0	162.0
Oct. 24 – Nov. 25	345.0	112.0	343.0	107.0	421.0	70.0	87.0	53.0
Nov. 26 – Dec. 23	327.0	115.0	300.0	88.0	240.0	54.0	142.0	459.0
Dec. 24 – Jan. 07, 1993	0.0	0.0	0.0	0.0	0.0	0.0	358.0	557.0
Jan. 08 – Jan. 26	360.0	125.0	330.0	107.0	320.0	71.0	60.0	178.0
Jan. 27 – Feb. 22	140.0	52.0	120.0	36.0	212.0	73.0	85.5	508.0
Feb. 23 – Mar. 29	0.0	−6.0	0.0	**−2.0**	0.0	−14.0	299.0	38.0
Mar. 30 – Apr. 26	0.0	−2.0	230.0	87.0	250.0	590.0	0.0	−36.0
Apr. 27 – May 25	99.0	35.0	162.0	58.0	220.0	665.0	469.0	91.0
May 26 – Jun. 24	45.0	23.0	130.0	48.0	165.0	29.0	40.0	24.0
Jun. 25 – Jul. 23	50.0	27.0	72.0	29.0	110.0	21.0	52.0	31.0
Jul. 24 – Aug. 25	60.0	23.0	39.0	13.0	105.0	18.0	50.0	17.0
Aug. 26 – Sep. 29	13.5	4.0	0.0	−7.0	95.5	12.0	99.5 +	39.0
Sep. 30 – Oct. 29	30.0	15.0	58.0	53.0	12.0	7.0	68.0	30.0
Oct. 29 – Nov. 30	15.0	10.0	29.0	7.0	29.5	10.0	165.5 +	46.0
Dec. 01 – Dec. 29	60.0	22.0	52.0	32.0	61.0	15.0	415.0	136.0
Dec. 30 – Jan. 26 , 1994	0.0	−2.0	70.0	21.0	0.0	−4.0	100.0	44.0
Jan. 27 – Feb. 28	0.0	0.0	0.0	−1.0	0.0	0.0	70.0	31.0
Mar. 01 – Mar. 25	48.0	19.0	0.0	0.0	0.0	0.0	62.0	24.0
Mar. 26 – Apr. 26	136.0	74.0	215.0	95.0	130.0	35.0	90.0	49.0
Apr. 27 – May 27	114.0	62.0	366.0	148.0	282.0	85.0	123.0	52.0
May 28 – Jun. 28	73.0	32.0	190.0	67.0	170.0	36.0	105.0	49.0
Jun. 29 – Jul. 26	75.0	24.0	34.0	15.0	130.0	25.0	95.0	44.0
Jul. 27 – Aug. 26	27.0	10.0	47.0	15.0	150.0	25.0	85.0	45.0
Aug. 27 – Sep. 26	17.0	10.0	24.0	5.0	120.0	20.0	60.0	45.0
Sep. 27 – Oct. 28	0.0	0.0	0.0	0.0	0.0	0.0	70.0	5.0

Negative values generally represent increases in well water levels that were not pumped out and have been omitted from the attached graphs. Where the negative value has been highlighted, the water level in the monitoring well actually dropped since the last pump out period.

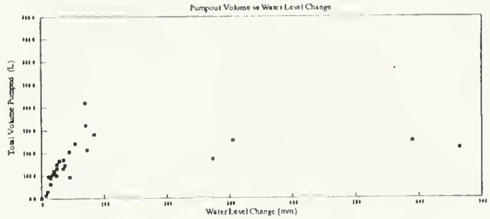
Britannia Lysimeter 1



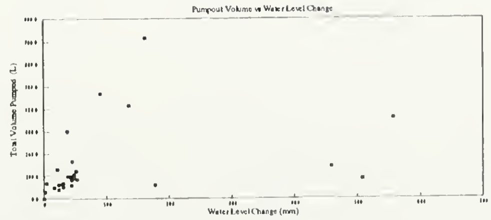
Britannia Lysimeter 2



Britannia Lysimeter 3



Britannia Lysimeter 4



APPENDIX F

TOTAL INFILTRATION BY SEASON

TABLE F.1 BRITANNIA LANDFILL SITE TOTAL INFILTRATION BY SEASON JUNE 1992 TO OCTOBER 1994

Britannia	Precipitation		Lysimeter 1		Lysimeter 2		Lysimeter 3		Lysimeter 4	
	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)
Jun 92 – Aug 92	259.0	10.2	49.3	1.9	26.2	1.0	47.2	1.9	17.3	0.7
Sep 92 – Nov 92	343.6	13.5	45.7	1.8	50.6	2.0	56.1	2.2	86.3	3.4
Dec 92 – Feb 93	152.9	6.0	89.0	3.5	80.7	3.2	83.0	3.3	69.4	2.7
Mar 93 – May 93	149.5	5.9	10.6	0.4	42.1	1.7	50.6	2.0	82.6	3.3
Jun 93 – Aug 93	274.1	10.8	16.7	0.7	25.9	1.0	40.8	1.6	15.3	0.6
Sep 93 – Nov 93	199.2	7.8	6.3	0.2	9.3	0.4	14.8	0.6	35.8	1.4
Dec 93 – Feb 94	110.0	4.2	6.5	0.3	13.1	0.5	6.6	0.3	62.9	2.5
Mar 94 – May 94	213.6	8.4	32.1	1.3	62.5	2.5	44.3	1.7	29.6	1.2
Jun 94 – Aug 94	203.0	8.0	18.8	0.7	29.2	1.1	48.4	1.9	30.6	1.2
Sep 94 – Oct 94	84.2	3.3	1.8	0.1	2.6	0.1	12.9	0.5	14.0	0.6

Not a complete season

TABLE F.2 GUELPH LANDFILL SITE TOTAL INFILTRATION BY SEASON
OCTOBER 1991 TO OCTOBER 1994

Guelph	Precipitation		Lysimeter 1		Lysimeter 2		Lysimeter 3	
	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)
Oct 91 – Nov 91	118.6	4.7	0.0	0.0	0.0	0.0	0.0	0.0
Dec 91 – Feb 92	149.1	5.9	149.7	5.9	140.2	5.5	208.2	8.2
Mar 92 – May 92	222.7	8.8	155.8	6.1	138.8	5.5	88.5	3.5
Jun 92 – Aug 92	371.4	14.6	119.5	4.7	51.0	2.0	57.6	2.3
Sep 92 – Nov 92	333.7	13.1	183.7	7.2	189.2	7.4	144.7	5.7
Dec 92 – Feb 93	201.3	7.9	88.8	3.5	123.8	4.9	108.0	4.3
Mar 93 – May 93	178.7	7.0	135.4	5.3	180.3	7.1	96.3	3.8
Jun 93 – Aug 93	269.5	10.6	42.6	1.7	62.8	2.5	58.1	2.3
Sep 93 – Nov 93	221.8	8.7	2.9	0.1	18.2	0.7	108.1	4.3
Dec 93 – Feb 94	157.0	6.2	4.5	0.2	23.6	0.9	92.7	3.6
Mar 94 – May 94	287.0	11.3	106.6	4.2	248.2	9.8	202.7	8.0
Jun 94 – Aug 94	223.1	8.8	69.6	2.7	97.8	3.9	52.9	2.1
Sep 94 – Oct 94	72.0	2.8	0.0	0.0	0.6	0.0	0.1	0.0

Not a complete season

TABLE F.3 BARRIE LANDFILL SITE TOTAL INFILTRATION BY SEASON OCTOBER 1991 TO OCTOBER 1994

Barrie	Precipitation		Lysimeter 1		Lysimeter 2		Lysimeter 3	
	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)
Oct 91 – Nov 91	111.6	4.4	18.3	0.7	0.0	0.0	24.2	1.0
Dec 91 – Feb 92	145.5	5.7	95.9	3.8	68.7	2.7	61.7	2.4
Mar 92 – May 92	137.1	5.4	98.6	3.9	66.0	2.6	73.7	2.9
Jun 92 – Aug 92	244.5	9.6	46.7	1.8	24.8	1.0	21.8	0.9
Sep 92 – Nov 92	271.2	10.7	175.6	6.9	41.8	1.6	83.1	3.3
Dec 92 – Feb 93	282.8	11.1	138.3	5.4	48.7	1.9	78.9	3.1
Mar 93 – May 93	195.4	7.7	374.7	14.8	72.7	2.9	322.2	12.7
Jun 93 – Aug 93	241.1	9.5	71.7	2.8	45.8	1.8	36.4	1.4
Sep 93 – Nov 93	244.3	9.6	98.4	3.9	31.2	1.2	70.6	2.8
Dec 93 – Feb 94	188.0	7.4	106.8	4.2	29.7	1.2	46.4	1.8
Mar 94 – May 94	184.6	7.3	119.3	4.7	31.6	1.2	70.3	2.8
Jun 94 – Aug 94	171.6	6.8	70.6	2.8	57.7	2.3	63.8	2.5
Sep 94 – Oct 94	135.0	5.3	7.9	0.3	11.6	0.5	7.7	0.3

Not a complete season